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THE STATE HIGHWAYS OF CALIFORNIA

AN ENGINEERING STUDY

CONDUCTED JOINTLY BY THE

Automobile Club of Southern California

AND THE

California State Automobile Association

JULY, 1920 - JANUARY, 1921

Copyrighted, 1921
by the
Automobile Club of Southern California
Los Angeles, Cal.

California State Automobile Association
San Francisco, Cal.

45451
1921

TABLE OF REPORTS

JOINT REVIEW OF DETAILED ENGINEERING REPORTS

OF THE

AUTOMOBILE CLUB OF SOUTHERN CALIFORNIA

AND

CALIFORNIA STATE AUTOMOBILE ASSOCIATION

ON THE

CALIFORNIA STATE HIGHWAYS

BY

J. B. LIPPINCOTT, Consulting Engineer,
Los Angeles, Cal.

H. J. BRUNNIER, Consulting Structural Engineer,
San Francisco, Cal.

C. DERLETH, Jr., Civil and Consulting Engineer,
Berkeley, Cal.

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San Francisco, Cal.

1921

I. Why Are California Automobile Clubs Interested?

The combined membership of the two State Automobile Associations exceeds 71,000. It is the purpose of these clubs to promote better highways and to advance and protect the interests of the automobile public. These two corporations have given substantial aid to secure the adoption of an aggregate of $73,000,000.00 of State and $42,000,000.00 of county bonds for highways; a total of $115,000,000.00. About half of this great sum remains unexpended. The State now has available nearly $39,000,000.00 for future work without the Federal aid contributions.

The clubs have taken keen interest in the passage of the Motor Vehicle Act and all general road legislation. Under the Motor Vehicle Act, members of the automobile associations are contributing in license fees a total of $760,000.00 annually to the State. This fund is divided equally between the State Highway Commission and the counties, and is available for road maintenance; therefore, the two institutions have a vital interest in the policy of the State Highway Commission. This policy not only has a direct bearing on the taxation of 535,000 automobiles and 35,000 trucks in the commonwealth, but also involves the future life and efficiency of the highways. The clubs are gravely concerned with the safety of the motoring public and feel a responsibility to the public in all projects connected with motor traffic.

The two associations realize the difficulties under which the State Highway Commission was compelled to pursue its earlier work. The construction programs of 1913, 1914, and 1915 are highly commendable. The mileage of roads built in the periods enumerated, in the face of an unsaleable 4% State bond, is a most creditable achievement. Cleanness of administration and absence of scandal have been noticeable. Wilful waste and extravagance cannot be charged and honesty of purpose is freely admitted.

Failures of paved highways in California have become frequent in the past two years. In consequence criticism of State Highway standards and State construction methods has been so general that the Board of Directors of the two clubs have considered it timely to institute an engineering and economic study of all the paved State highways to determine their present condition, their sufficiency in width and the adequacy to carry the ever-increasing volume and weight of traffic.

Incompleted sections of main trunk and lateral highways; the addition of an extensive mileage to the original program; the costs of work and the possibility of completing the system with the funds available furnished additional motive for this investigation.

The Governor of California was invited to appoint a State representative to act with the engineers of the automobile clubs, but declined since a similar investigation has been authorized by him under the direction of the Federal Bureau of Roads. However, the State Highway Commission has cheerfully furnished from its records all data that has been requested.

The engineers of the Automobile Clubs began their studies in July, 1920. The work has been continuous and uninterrupted up to the present time, and involves expenditures exceeding $30,000.00. Valuable data has been collected concerning weight, speed and volume of traffic; detailed inspections have been made of all paved roads on the State system; laboratory tests are being conducted at the State University; an elaborate highway bibliography has been assembled. In addition, the engineers of the two clubs have prepared extensive reports which have been filed with the respective organizations.

Mr. J. B. Lippincott, Consulting Engineer for the Automobile Club of Southern California, acknowledges the assistance and co-operation of the following gentlemen:

Committee on Sub-Base:

Robert Morton, Highway Engineer, San Diego County, Chairman.
Lawrence Moye, County Surveyor, Tulare County.

Committee on Thickness, Width and Reinforcement of Concrete Slab:

Charles Petit, County Engineer, Ventura County, Chairman.
Charles Derleth, Jr., Dean of Civil Engineering Department, University of California, Berkeley.
Owen O'Neill, County Engineer, Santa Barbara County.

Committee on Maintenance:

George Jones, Road Commissioner, Los Angeles County, Chairman.
E. E. East, Road Engineer.
S. H. Finley, Supervisor, Orange County.

Committee on Laws:

D. R. Faries, Attorney for the Automobile Club of Southern California, Chairman.
Watt Moreland, Truck Manufacturer.
C. H. Richards, Engineer.

While these reports may seem critical, it has been the first object to be constructive in criticism. Where road failures have been found, these reports attempt a determination of the cause and indicate possible remedies; this with a sincere desire to profit by successes and failures made, that California's future roads may be more substantially constructed to meet the requirements of an unparalleled increase and change in the character of traffic.

The brief discussion following is a synopsis of the various matters covered and analyzed in detail in the two reports referred to:

I. Why are California Automobile Clubs interested? (See page one.)
II. Promises made by the Highway Commission.
III. Highway Commission policies.
IV. Present condition of the State Highways.
V. Recommended types of construction.
VI. Costs and maintenance.
VII. Highway bonds and life of pavements.
VIII. Present and future traffic—traffic laws and their violation.
IX. Comparison of California Highways with those of other states.
X. Research and experimental investigation.
XI. Public opinion.
XII. Conclusion.

II. Promises Made by the Highway Commission

Records in the offices of the Automobile Associations show that prior to the July, 1919, election on the $40,000,000.00 bond issue, the California Highway Commission agreed to carry out the following construction program:

1. To complete all gaps and grade or pave all main trunk highways. These were definitely specified in the campaign previous to the 1919 election and involved 58 different sections.

2. To take over and construct entirely at State expense the county lateral system. These also were definitely specified for eight different sections

3. Thirty-one additional roads were listed and added to the bond issue as desirable roads. As many of them were to be built as the balance of funds would permit.

The Automobile Associations, having always been very active in the promotion of good roads, finding that the two original bond issues (the first for $18,000,000.00 and the second for $15,000,000.00) had not completed any of the main trunk lines between large centers of population (either along the coast or through the great inland valleys), were very insistent with the Highway Commission that a definite program be established if these associations were to go before the public again and spend time, money and effort in aiding the California Highway Commission to carry the $40,000,000.00 bond issue to a successful conclusion. Upon these understandings the above schedule was adopted as a program for the 1919 campaign. Facts show that the program as agreed upon is not being fulfilled.

III. Highway Commission Policies

The Commission has lacked foresight and vision by failing to carry out adequate and sufficient experimentation, research and investigation on a broad and comprehensive scale. It has not taken advantage of the few experiments it did make.

Until October, 1920, the Highway Commission followed a rigid policy. It used practically the same type of construction throughout the State, irrespective of the requirements of traffic, subsoil and drainage. Such a policy is economically and structurally unsound and open to grave criticism. Even the last pronouncements of October, 1920, propose a specific requirement of steel bar reinforcement for all concrete roads, no matter how the subsoil conditions may vary.

The Commission apparently has no stated program directed toward aiding county highway departments. It should adopt an adequate and liberal policy at once, that the counties may profit by the successes and failures in State Highway experience. The selection of type of road, width and thickness, reinforcement, suitable materials for construction, standard structures, surfacing, and numerous other details are of grave importance to the taxpayers of every county. Highway routings, bridges, etc., are so closely related to possible future State Highway locations that they demand uniform and concerted action between State and county if wasted effort and consequent additional expense are to be avoided.

It is a matter of common knowledge that the California Highway Commission has failed to profit by a very varied and costly experience taught by innumerable failures of 4-inch concrete roads. Despite these failures it has continued to build the light 4-inch road sections in numerous instances under practically the same conditions upon heavy subsoils of questionable and uncertain character. California has continued a 4-inch pavement program when other states increased the thickness to 6 inches and 8 inches.

Through a headquarters policy which must be classed as both narrow and short-sighted, the responsibility of the division engineer has been so circumscribed that at times his work has resolved itself into mere routine, such as the transmission of bill schedules, work and purchase orders and general requests for headquarters' approval. The position of division engineer is an important one, but he has lacked the authority to decide pressing and local questions. He has been obliged to refer the most minor items to Sacramento for decision. This robs the division of its individuality, takes away that responsibility which naturally should belong to the division engineer; kills his initiative and therefore effects the entire division organization.

Just criticism of the State Commission arises from the constantly recurring delays in payments of accounts of all kinds. Bills for supplies and general expense are frequently held either in the office of the Highway Commission or of the Board of Control for months, and it is difficult to find any logical reason for this unbusinesslike procedure. Contractors' prog-

ress payments and final estimates have suffered in the same way, frequently causing great hardship if not serious financial loss to the contractor.

The Commission's attitude toward highway contractors of excellent standing has been the cause of severe criticism from contractors of the soundest reputation. Highway contractors in the past have found little profit in highway work. The list of contracting firms who have become bankrupt is astonishing. Numerous instances of rigid and drastic rulings involving considerable losses to the contractor have been cited causing some contractors to claim that the Commission's policy has been one of alienation rather than one of co-operation. Such policies can only have one result; an increase in the future prices bid.

The experience of the State Highway Commission is that day labor work is not economical, therefore the contractor who must build our highways should be dealt with fairly and be encouraged to undertake the work under conditions which may realize him some profit. Any other course is not in the interest of the State or of ultimate economy.

There is much room for improvement and development in the Commission's future attitude towards: 1. Accounting and cost keeping; 2. Equipment accounts; 3. Amendments to specifications and contracts; 4. Yearly traffic records; and a number of other pertinent subjects, all of which are dealt with in detail by the Club reports.

IV. Present Condition of the State Highways

Our examinations do not justify the statement made by the Chairman of the Highway Commission on June 19, 1920, viz., "that in his opinion 90% of the State highways thus far built in California are as good as the day they were laid." In Southern California, field inspections indicate that as high as 30.5% of the concrete pavements are in poor condition, requiring reconstruction either now or at an early date. An additional 19.3% is in only fair condition, serious failure having already begun. This leaves only 50.2% of the pavements in this section in what may be termed good condition. In general, inspections in the southern part of the State have indicated higher percentages of failure than in the northern portion, where failure area is only 17.7% and pavements in fair condition aggregate 20%, leaving 62.3% of these pavements in good condition.

Inspections show that pavement failures are closely related to soil conditions and imperfect drainage. In Southern California, of roads built on clay and adobe soils, 70% have failed, and in Northern California approximately 61%. On sand, gravel, decomposed granite and similar soils from 70% to 75% of the concrete roads are in good condition.

V. Recommended Type of Construction

Since these investigations were begun by the Automobile Clubs the State Highway Commission has increased the thickness of its standard pavement to 5 inches and proposes to reinforce it all. A 5-inch concrete slab is not thick enough to meet heavy traffic requirements.

We cannot endorse a policy that contemplates the use of expensive steel reinforcement irrespective of conditions of sub-soil, traffic and drainage. The amount of steel reinforcement that is practical and economical is variable. The amounts specified by the Highway Commission are too much where sand, gravel, decomposed granite and similar soils are encountered and too little on boggy subgrades or on clay and adobe sub-soils, especially where the thin 5-inch concrete minimum slab now specified is used.

It has been stated by the Chairman of the Highway Commission that: "The consensus of opinion of our engineers is that the reinforcing of the concrete highway is the equivalent of thickening it at least two inches." Tests show that a 6-inch plain concrete slab has a greater traffic capacity than 5-inch sections reinforced as proposed; therefore this statement has little foundation in fact.

The high maintenance charges and reconstruction costs which 4-inch and 5-inch pavements have required during the past seven years, particularly where the sub-soil is clay or adobe, lead to the inevitable conclusion that it is more economical to build thicker and more substantial pavements.

We must expect enormously increased truck traffic. Wheel loads and speeds will increase unless legislation and larger license fees prevent. Congested truck traffic already requires an 8-inch minimum concrete thickness with substantial reinforcement wherever the subgrade demands it.

For trunk roads we recommend pavements of an average thickness not less than 6 to 8 inches, dependent upon subgrade, drainage and traffic requirements. Wherever the sub-soil is treacherous and yielding, these concrete pavements require an amount of reinforcement proportional to the foundation difficulties to be overcome.

The Highway Commission should have paid greater attention to the preparation of subgrades. Experience has shown that modern traffic will inevitably crack thin concrete pavements on subgrades of heavy clay or adobe unless every precaution is taken to provide drainage and to keep the moisture content as nearly constant as possible in the subgrade materials. It is recommended that clays and adobes be adulterated by rolling into them such materials as sand, gravel, and broken stone. Everything should be done that will tend to limit the tendency for change in adobe volume with change in moisture content. The adulteration and impregnation of clay and adobe sub-soils should always be extended to each side of the concrete slab to provide an equally secure foundation for side shoulders. These side foundations and shoulders should be not less than 3 feet in width wherever the clay or adobe is questionable. The type of reinforcement used by the California Highway Commission cannot prevent longitudinal cracks on adobe; it tends only to hold the broken slab together.

While rock or gravel shoulders, oil bound and sealed, are recognized as unsatisfactory and uneconomical, if built for the purpose of widening a concrete road, it is our belief that such type of shoulder should be provided on all adobe and heavy clay sub-soil sections irrespective of width of pavement, primarily for the purpose of preventing storm water from working down and under the pavement to its detriment and possible destruction. In addition to keeping the moisture content more uniform, shoulder construction gives lateral support to the sides of pavement thus reducing the known tendency to break down along the edges. With wider concrete roads this type of shoulder would only be subjected to turnout traffic; in consequence, a longer span of life **under proper maintenance may be expected.**

The cost of any measure is justified which tends to reduce or prevent longitudinal and corner cracks where pavements rest on flexible soils. Greater width in a pavement and steel reinforcement cannot alone be relied upon to prevent longitudinal and corner cracks. Shoulders must protect the edges and sides of the pavement.

Greater width of permanent paved roadway is, however, of extreme importance. Fifteen-foot pavements without shoulders are unsatisfactory and dangerous. Modern trucks with an 8-foot body width cannot pass on a 15-foot roadway without inviting collision and accident. The width of all double track highways should never be less than 18 feet on tangents; they should be widened on curves and grades. Future traffic demands a minimum width of 20 feet for every important road. Near cities, or wherever the traffic is heavily congested, pavement widths should be not less than 24 feet.

We cannot include technical details in this summary; therefore in the matter of the control of transverse cracks we merely state that properly designed expansion joints should be provided at stated intervals.

The State should adopt a high standard of concrete mixture, developing higher ultimate strength than has heretofore obtained. Ten States use the same mixture as California and thirty-seven use a richer mix.

VI. Costs and Maintenance

Independent of all other considerations, it is illuminating to examine the probable life of 4-inch pavements completed in 1914-1915 and the ultimate cost at the end of the average life of the bonds issued to cover their initial cost. The first cost of these pavements 15 feet wide and 4 inches thick averages approximately $7,073.00 per mile (pavement and engineering costs only).

Developing maintenance costs, including surfacing, until they reach a point where it is no longer sound financially to continue repairs, we find that economically these pavements have an average life of approximately 11 years. Adding interest to the original cost, plus maintenance, together with reconstruction costs and additional interest and maintenance to the average bond life noted (in this case 25 years) the ultimate costs are obtained. These ultimate (or 25-year) costs average approximately $67,800.00 per mile.

The ultimate or 25-year costs of pavements laid in 1914-1915, if these had been constructed to a thickness of 7 inches, with proper treatment of adobe subgrade, and using reinforcement where necessary over approximately half the mileage, would have been $53,050.00 per mile. This seems a conclusive demonstration of the type of pavement that would have provided the soundest investment of the people's money for the life of the bond. This analysis, therefore, confirms the recommendation as to thickness of pavement made in V.

VII. Highway Bonds and Life of Pavements

For the first and second bond issues the last bonds will be retired in 1962. Probably long before this time many of our present pavements will have become either worn out or obsolete and their general reconstruction will be necessary. Based on sound financial policy, pavements should live as long as the average life of bonds with which they are built. Some of our 4-inch pavements have broken down in 4¼ years; practically before the retirement of any of the bonds had begun. It is estimated that all of our roads will need replacement at the end of their economical life. The total length of life of our present roads is a matter of judgment and is speculative, but the economical life of the earlier pavements is definitely determined to average about eleven years.

It is important to build more permanent roads with shorter life bonds. In this connection it is interesting to note that the State of New Jersey prohibits the use of a bond of a life over 20 years for the construction of any type of road. In that State the limit for sand and gravel road bonds is 5 years; for macadam, 10 years; for bituminous concrete, 15 years; for block or sheet asphalt, on concrete, and plain concrete 6 inches thick, 20 years.

With our State bonds running many years beyond a 20-year life, it behooves us to consider the seriousness of a short life for our 4-inch pavements and to fundamentally change our policies in this regard.

VIII. Present and Future Traffic—Traffic Laws and Their Violation

The number of automobiles in California has increased from 98,399 in 1913 to 535,000 in 1920. In the same interval trucks have increased from 5,299 to 35,000. We may confidently expect a great increase in the growth of the number of trucks. Their size, weight and future speed is an uncertain question.

During the past four months, 2,000 trucks have been weighed; 256 of these were found to be overloaded, in some instances as much as 100%. 500 trucks weighed on public scales gave loadings on each rear wheel ranging from 4,275 lbs. for 1-ton trucks to 11,280 lbs. for

5-ton trucks. Truck operators observe little relation between the manufacturer's rating and the load carried. As one expressed it: "They would haul any load they could start."

The California State law provides a maximum weight per inch of tire in contact with the road of 800 lbs. By actual measurement on 500 trucks the average loads per inch width of tire on one rear wheel ranged from 831 lbs. on 1½-ton trucks to 1,090 lbs. on 5-ton trucks. The maximum load per inch width of tire measured was 1,840 lbs.

It is not so important to rigidly adhere to a rule limiting the maximum load of 800 lbs. per lineal inch of tire in contact with the pavement. It is far more important to limit the maximum load put upon any one wheel. The maximum load usually found on rear wheels of 3½-ton and 4-ton trucks is approximately 10,000 lbs. The speeds of these trucks averaged 18.4 miles per hour for 1-ton capacity to 13 miles per hour for 6-ton trucks.

While the State of California has built roads that have been demonstrated to be too frail and too narrow, it has also completely neglected to enforce the laws relative to overloading the pavement slab. It is apparent that if truck operators are permitted to use the highways without police supervision a few unreasonable truck drivers or operators will wreck any road system that may be built. Thinking people recognize that such a policy is improper, short-sighted and suicidal. There must be co-operation between truck dealers, truck operators and the State authorities in the enforcement of proper traffic laws.

California should adopt a uniform Motor Vehicle Law. Such a law is necessary for interstate traffic. Manufacturers cannot be expected to design special trucks to meet different State laws.

It is equally important that speed regulations should be enforced for trucks. The speeds at which these heavy loads travel on public highways produces impact. This road shock is especially destructive to the pavement.

It seems a proper time has come to consider modifications to the present Motor Vehicle Tax as well as to the law governing weights of vehicles in view of the considerable additional mileage to be added to our existing paved highways and the steadily increasing maintenance and reconstruction costs. A more equitable adjustment of the tax will be secured by proportioning fees to be collected more directly to those vehicles which use the highways the most as well as to those vehicles which are most destructive.

Examination of motor tax enactments in other states leads to the conclusion that the present California taxes are extremely moderate and not in accord with more equitable tendencies.

IX. Comparison of California Highways With Those of Other States

It is a fact, established by correspondence with 35 States, that California design is far behind modern specifications in use elsewhere for width, thickness and richness of concrete mixture. This fact in itself is ample cause for reflection. Until October, 1920, after these investigations began, California was building a standard pavement 4 inches thick. The present standard is 5 inches, reinforced. Of the thirty-five States for which we have records, no other State has a standard pavement as thin as 5 inches. Many other States started their highway program five and more years ago, with thin and narrow slabs and lean mixes of concrete, but they have developed a more substantial standard construction as they saw the growth and development of traffic. Their pavements are now wider, thicker and richer than our own. It is true that California has changed its concrete mix from 1 : 2½ : 5 to 1 : 2 : 4, and has very lately increased slab thickness to 5 inches and introduced reinforcement, but in making these changes California has been slower to act and has not gone so far as other states in the building of heavier and more durable pavements.

X. Research and Experimental Investigations

The California Highway Commission has not sufficiently and adequately conducted research and experimentation. In work of the magnitude of our highway program, the Commission should set aside a budget of sufficient funds for the continuous study of special problems. Some of these are:

1. Relative capacity to distribute pressure on sub-soils by

   a—rigid pavements of concrete.
   b—asphaltic pavements.
   c—macadam.

2. Tests of heavy clays and adobes.
3. Investigation of sub-soil drainage,

   a—in clays and adobes.
   b—in compressible soils in the presence of freezing and thawing.

4. Level records on pavements from selected sites.
5. The effects of alkali.
6. Tests on full sized pavements to determine more fully the relative advantages of reinforcement vs. greater thickness of slab and varying richness of mix of concrete; a study of different types of reinforcement.
7. Studies of the absorptive power of adobe and clay to take water out of the bottom of a freshly poured concrete slab.
8. A study of the mechanical adulteration of clay and adobe subgrades; an inquiry into possible chemical treatment.
9. Traffic studies; the effect of impact; of roughness, of surface of pavement; design of truck, character of tires, speed, etc.

These and other tests suggested by modern practice should be programmed. They would be expensive; would take time and would require a specially trained staff of assistants, but the magnitude of the work justifies such expenditures and would teach the Commission and its engineers how to avoid otherwise costly mistakes.

XI. Public Opinion

The public has not been sufficiently informed that adequate permanent roads would cost more than the estimates and bond issues have indicated. To achieve mileage of highway, roads have been built that are dangerously narrow and entirely too frail. In the three bond issues a total of 5,560 miles of State roads are proposed; only 1,402 miles have been paved, or 25%. Practically no roads specified in the third bond issue have been built. Public opinion in California demands more permanent types of construction rather than mileage of highways. County roads where the taxation is more directly placed on the beneficiaries are in some instances better roads than those built by the Highway Commission. We predict that the California public will not continue to support frail construction on long life bonds.

XII. Conclusion

This report has called attention to numerous failures of concrete roads, but it is not intended to convey the impression that the undersigned are opposed to the construction of concrete highways. The contrary is true. We believe that the most satisfactory type of pavement to stand heavy traffic conditions, particularly on insecure foundations, is an adequately and properly built concrete slab.

The California Highway Commission, while perhaps not legally and technically responsible for some of the conditions described in this report, is however, the State authority having general supervision and jurisdiction over our expensive highway program. At least it is the advisory authority to which all branches of the State Government turn. The Commission and its engineering staff must take direct responsibility for the present highway situation. Judging from past experience, all future work should be subject at intervals to careful inspection and review by competent representatives of the people.

Detailed reports have been submitted to the Automobile Club of Southern California and the California State Automobile Association by their respective engineers and the above is a general review and summary made by the undersigned.

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AUTOMOBILE CLUB
OF
SOUTHERN CALIFORNIA

ENGINEERING REPORT
ON
CONDITION
OF
SOUTHERN CALIFORNIA STATE HIGHWAYS

BY
J. B. LIPPINCOTT
CONSULTING ENGINEER

LOS ANGELES — 1921

AUTOMOBILE CLUB OF SOUTHERN CALIFORNIA

(INCORPORATED 1900)

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AUTOMOBILE CLUB OF SOUTHERN CALIFORNIA
1344 South Figueroa Street
LOS ANGELES, CAL.

July 20, 1920.

Roads and Highways Committee
H. W. KELLER, Chairman
H. G. MILLER
E. D. LYMAN

Mr. J. B. Lippincott, Consulting Engineer,
Automobile Club of Southern California,
Los Angeles, California.

Dear Sir:

You are requested to make an inspection of the **present condition** of that portion of the California State Highways south of the Monterey and Fresno County lines including the Owens Valley. It is also desirable that you compile all relative historical data that is available concerning the building of these roads.

You are instructed in addition to take a traffic census on these roads, particularly ascertaining the weight and speed of trucks.

As the Automobile Club of Southern California has been so active in the past in endorsing and aiding a progressive good road construction program in California, the directors of the Club feel it their duty and desire not only to post themselves as to the permanence and maintenance cost of this work but they wish also to spread this information before the 46,000 members of the Club.

Your study should be distinctly scientific, impartial and constructive in its character. It should make definite recommendations, where your findings indicate the propriety thereof, as to improvements in construction methods, standards, and upkeep, suggesting modifications, if any are required, of the traffic laws of the State.

You should keep in mind the enormous development of interurban and rural traffic that has occurred during the past years on our California roads, being mindful that this is a new economic feature that should be encouraged and provided for within the reasonable financial ability of our taxpayers.

You will employ such expert assistants and office force and perform such work as from time to time your judgment may indicate is necessary.

In concluding, this subject should be approached by you and your assistants with an open mind, with a view of the presentation of a fair and impartial helpful report. It should be presented at the earliest possible date. We desire to co-operate with the representatives of the California State Automobile Association who are making a similar study of the roads of the northern part of the State.

Yours very truly,
(Signed) H. W. KELLER,
Chairman of Roads and Highways Committee.

10-6 Pile trestle on Rincon Road north of Ventura, Ventura County.

10-7 Riprap wall rebuilt by Highway Commission north of Ventura, Ventura County.

10-8 Floor of pile trestle on Rincon Road north of Ventura, Ventura County.

Letter of Transmittal

AUTOMOBILE CLUB OF SOUTHERN CALIFORNIA
Office of the Chairman
Roads and Highway Committee

To the Directors of the
Automobile Club of Southern California,
Los Angeles, California.

January 10, 1921.

Gentlemen:

It having become manifest to the Directors of the Automobile Club of Southern California that the State Highways constructed under the several bond issues were rapidly deteriorating after a very short life, instructions were issued to your Roads and Highways Committee to employ competent engineers and undertake a study of the entire State system. Simultaneously, the California State Automobile Association, a motoring organization, with headquarters in San Francisco, and upon their own initiative, sent a committee to Los Angeles, to discuss the present condition of the State Highways, and as a result of this joint meeting it was decided by the two motoring organizations to undertake this study jointly. It was also decided that a summary of the forthcoming report should be prepared by the engineers engaged in the work, and after approval by the Directors of the Northern and Southern Clubs it should be published for the information and enlightenment of the people of the State of California.

This report is herewith transmitted for your consideration. In the preparation of the report there has been expended in time more than five months. It can be said of the report that it is the most extensive and comprehensive study that has been made in the United States of this important subject to this date. The data collected is voluminous and technical and is accompanied by photographs, tables, maps, diagrams, etc. This data is so valuable and has been acquired at such great cost that it should be published in book form so as to make it readily available as a reference work for the other states of the Union, the National Government, universities and colleges.

The consulting engineers of the two organizations, Mr. J. B. Lippincott, representing the Southern Club, and Messrs. Howe and Peters of San Francisco, representing the Northern Club, directed the study in their respective territories. Associated with them were Professor C. Derleth of the Department of Engineering of the University of California, Mr. H. J. Brunnier, Consulting Engineer of San Francisco, and ten other well-known engineers and experts, whose names are mentioned in the joint summary report.

A perusal of the main report and the summary discloses the following salient points and conclusions:

The report emphasizes what was already generally known, that the State highways of four-inch concrete were not only inadequate, but in many localities were badly and inefficiently constructed. That the highways built upon adobe soils began to fail almost as soon as completed. These adverse results did not escape the notice of the Highway Commission

for they inaugurated a series of experiments initially on the Calabasas Road, and at other points in the State, which were successful and overcame the defects of roads built upon adobe sub-bases. No advantage was taken by them of the knowledge so obtained, and they continued building the State system of four-inch concrete slab under a blanket specification. They are still building under a blanket specification. Since this investigation started, and not before, their specification has been altered from a four-inch slab to a five-inch slab with metal reinforcement. Whether the road traverses the granite range of the Sierra Nevadas or the marshes of the Pacific littoral, or the adobe plains of our interior valleys, the specification is unaltered. We find ourselves, at the end of four short years, with but 50% of our State roads, especially in Southern California, pronounced good, the remainder classified as fair and poor. And it must be taken into consideration that the determinations so arrived at were the result of a definition both liberal and charitable, and acceptable to the Commission's engineers.

The report shows further that the ultimate life of the State highways will not endure beyond eleven years, although the average redemption life of the bonds extends over a period of 25 years.

We have not only a heritage of bad roads, but an upkeep cost which is prohibitive. In one instance at least the upkeep, after four years, has equalled the original cost.

California was among the first of the states of the Union to build cement roads. Since that time about forty states of the Union have followed our example at least in their choice of material. These other states, unlike our conservative Highway Commission, discovered the inadequacy of a four-inch slab and adopted roads of greater width and with a six or eight-inch slab. There are today 35 states in this Union building cement roads whose specifications call for wider, thicker roads, and a richer cement mixture.

The report devotes considerable space to the charge of bad treatment received by the contractors at the hands of the Highway Commission, and this is given as one of the reasons for the excessive costs of much of the highway work. Since our engineers' report was rendered a meeting has occurred between the contractors building our State road work and the Commission and, as a result, nine causes of complaint have been eliminated. It is sincerely hoped that the changes effected will result in a better co-operation than has existed in the past and that it will be now possible for the State of California to build roads at a cost approximating those of other states, taking into consideration the respective specifications under which the roads are built.

The Highway Commission is justly charged with building inadequate roads, and persisting in such construction when it was evident even to the layman that the roads would not serve the increasing traffic and loads to which they were subjected. They failed to observe or profit by the example of other states and there has been an almost total lack of scientific research and experimentation on their part. The most serious accusation against them and no defense is available, lies in their neglect to safeguard the roads they builded. The evidence shows that in the rebuilding of one road they destroyed with their own trucks more miles than they repaired, and the destruction was halted by this organization. Although legislation was initiated and secured by the Commission to control the loads which might legally pass over the highways no steps were taken by the Commission, or any other department of the State Government, to enforce those acts. It can be safely asserted that the greatest factor in the rapid deterioration of our roads has been due to overloading of all kinds that has been indulged in by the public, without let or hindrance, by the State Commission. The roads were inadequate and ultimately would have succumbed to even a regulated traffic and loads, but their destruction was hastened by the failure of the State authorities to enforce existing statutes.

The whole question of road building is an economical one and the test that should be applied in every case is, will a given road or system of roads effect such a saving in haulage cost as to pay the interest on the bonds that built them and refund the cost of construction. The transportation of freight is today undergoing as great a metamorphosis as when we substituted for the stage coach and canal boat the steam locomotive. With the evidence before us we must concede that the motor truck has become a permanent part of our commercial life and national well-being. Road building in the United States received its first great stimulus from the invention of the automobile, and the first improved roads were built and designed largely to accommodate that class of travel. There followed in natural sequence the motor truck, and the roads designed for comparatively light traffic soon demonstrated their inability to carry the heavier loads imposed upon them. Today the transportation of freight by motor truck has assumed first importance, and the light vehicle is in a secondary relationship. Our roads of the future should be primarily designed to withstand the heavy loads they are and will be subjected to.

In the report rendered, the Highway Commission's past and present are freely criticised for their shortcomings but the criticism is constructive, and the remedies for the errors of the past are pointed out, and if followed will result in better and more durable roads.

Your Committee considers this an opportune time to inform the Board of Directors with reference to the mileage of the uncompleted portions of the contemplated State Highway System and the probable cost of such completion.

Messrs. Howe and Peters, Consulting Engineers, employed by the California State Automobile Association, and who assisted in the preparation of this report, furnish the following figures and estimates of cost for the completion of the State Highway System. They arbitrarily divide all the roads in the State under three classifications as follows:

1. Primary Roads:

Roads of primary importance are those uncompleted sections of the main trunk highway system connecting large centers of population, important county seats, and furnishing direct connection to the entire State boulevards;

2. Secondary Roads:

Those highways not yet completed which reach out from the main trunk system to connect with the minor centers of population and smaller county seats;

3. Roads Providing Limited Service:

Lines providing limited service are those which are considered unimportant at the present time, and which do not provide service commensurate with the investment involved.

Under this classification we have 3,978 miles of the State Highway System yet to be built, divided as follows:

1. Primary Roads	1,540.4	miles
2. Secondary Roads	818.6	"
3. Roads providing limited service	1,619.	"
	3,978.	miles

Assuming present costs of construction, it will require $143,898,000.00 to grade and pave the 3,978 miles of uncompleted roads. There is available today of State funds $39,000,000.00. Funds required to complete $104,898,000.00. The moneys on hand with actual Federal aid contributions will therefore complete only the primary roads, but will leave no funds to construct any of the remaining 2,437 miles of highway provided for in the Highway Acts of 1915 and 1919.

Included in the above tabulation is a road starting at Coachella-Riverside County, and terminating at Yuma. This particular road in its course traverses seven miles of wind-blown sand hills, constantly shifting and changing in form. This section was built by the Highway Commission in 1916 of 4-inch planks and at a cost approximating $100,000.00. The yearly maintenance of this road is $5,000.00—or $20,000.00 for the four-year period. Experience has shown that it is impracticable to keep this road open for travel during the frequent wind storms that prevail in that section. It is a formidable desert and but two wells are found midway between Holtville and Yuma. The Southern Pacific Railroad has twice been forced to move their tracks to the eastward to escape the engulfing sands. It is a perilous road even for the most experienced, but notwithstanding the dangers and adverse physical conditions, the Highway Commission persists in its attempt to maintain a road in its present location, although a feasible route exists between the points named.

Yours respectfully,
ROADS AND HIGHWAYS COMMITTEE.
By H. W. KELLER,
Chairman.

HWK/B

Engineering Report on the Condition of
CALIFORNIA STATE HIGHWAYS
By J. B. LIPPINCOTT
Consulting Engineer

Organization

The men engaged in this study of the roads are experienced engineers. All are technically trained. Mr. C. H. Richards, who is an associate in the engineering office of J. B. Lippincott, had charge of some of the heaviest construction work at the Los Angeles Aqueduct. He has built a number of paved roads in Southern California. He is a practical construction man. As the engineer in charge of the field work he has compiled the data as well as directed the details. He deserves much of the credit for what has been accomplished.

Mr. E. E. East not only has had charge of the building of many of the Southern California State roads, but was maintenance officer for their upkeep. He has inspected and classified them for this report.

Mr. J. B. Lippincott has had general supervision of this study. With him has been associated Prof. Chas. Derleth, Jr., Dean of the School of Civil Engineering at Berkeley. Prof. Derleth brings to this study years of highly trained observation and technical skill, as well as the experience of a practical construction engineer. The engineering laboratories at Berkeley have been made available for these investigations through the courtesy of Prof. Derleth.

Mr. Walter C. Howe, Consulting Highway Engineer of the firm of Howe & Peters, of San Francisco, has co-operated in reaching the general conclusions. Mr. Howe, in addition to his technical training as highway engineer, has had an extensive experience in municipal, county and State highway construction. He is the consulting engineer for the California State Automobile Association.

Mr. Standish L. Mitchell, Secretary of the Automobile Club of Southern California, and Mr. C. E. McStay, Field Secretary, have assisted in this study by the collecting of data and contributory information.

On July 29, 1920, a road conference was held under the auspices of the Automobile Club of Southern California, which was attended by representatives of the Northern Automobile Club and numerous county officials of Southern California, at which the general road program of the State and counties was outlined and the necessity of a general investigation was recognized. The following committees were appointed to assist in the work:

Committee on Thickness and Width of Slab and Reinforcement.

- Charles Petit, County Engineer of Ventura County, Chairman.
- Chas. Derleth, Jr., Dean of Civil Engineering Department, University of California, Berkeley.
- Owen O'Neill, County Engineer of Santa Barbara County.

Committee on Maintenance of Roads.

- Geo. L. Jones, Road Commissioner of Los Angeles County, Chairman.
- S. H. Finley, former Engineer of Orange County, now Supervisor.
- E. E. East, Road Engineer.

Committee on Sub-Base.

- Robert Morton, Highway Engineer of San Diego County, Chairman.
- J. B. Lippincott, Consulting Engineer.
- Lawrence Moye, County Engineer of Tulare County.

Committee on Trucks and Truck Laws.

David R. Faries, Attorney for Automobile Club of Southern California, Chairman.

C. H. Richards, Engineer.

Watt Moreland, Truck Manufacturer.

The reports of these various committees are attached hereto.

The Southern California Automobile Club at the time of its organization for the study of the State highway problems in California, invited the Governor of the State to appoint some representative to co-operate with the Club. The following letter was sent to the Governor:

AUTOMOBILE CLUB OF SOUTHERN CALIFORNIA
Office of the Secretary

August 6, 1920.

Hon. Wm. D. Stephens,
Governor of California,
Sacramento, Calif.

Dear Governor Stephens:

Actuated by a desire to perform a valuable service to the motoring public and to all taxpayers of the State of California, the Automobile Club of Southern California and the California State Automobile Association have become engaged in a most exhaustive study of highways already constructed, both State and county, throughout the State.

This engineering examination is under the supervision of our Consulting Engineer, Mr. J. B. Lippincott, in Southern California, and Mr. Howe, of the firm of Howe & Peters, of San Francisco, representing the California State Automobile Association, in Northern California.

On July 29th a meeting was held in this city under the auspices of this organization for the purpose of a general discussion of the matter and outlining a plan of procedure, at which were present the county highway engineers of the Southern California counties, together with Messrs. Lippincott and Howe, and the engineering staff organized by Mr. Lippincott for the carrying on of this work. Prof. Derleth, Jr., head of the Engineering Department of the University of California, has agreed to serve in an advisory capacity and to supervise the necessary research work.

It was particularly made clear to all present at this meeting that it was the intention of the two clubs to carry on this investigation entirely without prejudice or bias, and for the purpose of ascertaining the true condition of all highways throughout the State, and by the combined efforts of all parties interested in the investigation, to bring in an exhaustive report which we hope will be of real constructive value to the future road program, both State and county, of California.

It was the unanimous desire of all present at this meeting that you be requested to detail a representative of the State Engineering Department to actively participate in the work outlined for this highway study, and we would be pleased to have this request duly considered by you and to have such an appointment made.

For your information, Mr. Lippincott and our Field Secretary, Mr. McStay, have already discussed this matter informally with Mr. Darlington, Chairman of the State Highway Commission, prior to the above mentioned meeting.

We would sincerely appreciate your early consideration of this request.

Very truly yours,
STANDISH L. MITCHELL,
Secretary.

The reply to this letter is as follows:

CALIFORNIA HIGHWAY COMMISSION
Union League Bldg.

Los Angeles, Calif.,
Aug. 11, 1920.

Mr. Standish L. Mitchell, Secy.,
Automobile Club of Sou. Calif.,
Los Angeles, Calif.

My Dear Mr. Mitchell:

Your letter of the 6th inst., addressed to Governor Stephens, has been referred by him to this Commission for reply.

On June 24th the following telegram was sent by us to the Bureau of Public Roads:

> "The California Highway Commission believes that a complete study and report on the State Highway System of California should be made now by the field men and economists of the United States Bureau of Public Roads. An authoritative, impartial and comprehensive report on the California work, a project involving large expenditures and covering a period of nearly nine years, would be of great value both to California and the other States."

Since that time, Mr. MacDonald, Chief of the Bureau, has accepted our invitation to have an investigation made of the State Highway System of California and its expert engineers are now engaged in making a thorough and complete study of the highway work in all its various phases.

In view of this situation we feel it would be rather an indelicate thing for us to participate in another investigation which is to be carried on at the same time and which is designed to cover practically the same ground.

We wish to say again, however, that we will be very glad to furnish you complete data concerning the State highway work and are ready to put our own men to work compiling such data as you may require. In this fashion we will be able to assist you in a very practical way and hope you will not hesitate to call upon us for any information you may desire. Upon your request for such data or such information as you may desire, we will immediately have the same compiled or, if a conference is desired, we will arrange for such conference or conferences with the person or persons in our organization best fitted to give you the information you desire.

Very truly yours,
CALIFORNIA HIGHWAY COMMISSION.
C. C. CARLETON, Acting Secretary.

Arrangements have been made by the Automobile Club of Southern California for an audit of the accounts of the Highway Commission by the Tax Payers' League. This audit is now in progress but the results thereof are not now available (December 1st, 1920). The costs of construction and maintenance presented herewith are from data furnished by the California State Highway Commission. Fourteen per cent has been added to the figures showing original construction for overhead and incidentals. The percentage used by the Highway Commission for such charges on maintenance work is twenty per cent.

HISTORY OF CALIFORNIA STATE HIGHWAYS

The California Highway Commission

The people of the State of California adopted the "State Highways Act" of March 22, 1909, providing for the issuance of bonds to the amount of $18,000,000 for the construction and acquisition of a system of State highways by the State Department of Engineering. The routes to be selected by the Department of Engineering and built so as to constitute a continuous highway system, north and south, traversing the Sacramento and San Joaquin Valleys and along the Pacific Coast by the most direct and practicable routes, connecting the county seats through which it passes and joining the centers of population, together with such branch roads as may be necessary to connect therewith the several county seats.

The Department of Engineering consisted of an advisory board composed of the Governor as ex-officio member and chairman, the State Engineer, the General Superintendent of State Hospitals and the chairman of the State Board of Harbor Commissioners of San Francisco. The functions of this board were advisory.

In 1911 the Legislature passed what is commonly known as the Chandler Act, which added three more members to the Department of Engineering.

While the Chandler Act did not specifically so declare, yet it was tacitly understood at the time of its passage, that the three appointed members were to be chosen primarily for the purpose of actively carrying out the eighteen-million-dollar highway trust, and when appointed were named with their qualifications as such trustees in view.

In August, 1911, the Advisory Board adopted an enabling resolution designating Messrs. Blaney, Towne and Darlington the three appointed members as an Executive Committee to be known as the California Highway Commission, and vesting in such committee the handling of the work of constructing and acquiring the State highway system under the bond issue of 1910.

In the fall of 1911 the members of the commission, with the Highway Engineer, made a comprehensive tour of the State in order to obtain first hand impressions of the routes to be followed and the needs of the respective communities. They established seven division offices in different parts of the State, each in charge of a division engineer at Willits, Dunsmuir, Sacramento, San Francisco, San Luis Obispo, Fresno and Los Angeles. Actual road building operations were commenced in the summer of 1912.

The Legislature of 1913 passed California's first comprehensive act for the registration of motor vehicles and the licensing of operators thereof.

This act provided that one-half of the net proceeds should be devoted to the maintenance of State roads and highways.

After it had become effective, the Advisory Board imposed upon the California Highway Commission the further duty of maintaining the State highways.

In the year 1916 the people adopted the "State Highway Act of 1915" for a second State highway bond issue, in amount $15,000,000. The expenditure of the proceeds thereof was placed in charge of the California Highway Commission.

Finally the Legislature of 1917 gave the California Highway Commission statutory recognition and a legal entity by an amendment of the Department of Engineering Law, providing that the three appointed members of the Advisory Board shall compose a subdivision of the Department of Engineering designated as the California Highway Commission, and expressly prescribing their powers and duties.

This amendatory act also transferred all State roads, which had been constructed under special appropriations and which until 1917 had remained in charge of the State Engineer to the jurisdiction of the California Highway Commission.

Thus the California Highway Commission ceased to be an executive committee of the Advisory Board and has become a statutory body in immediate control and supervision of all State road and highway activities of California.

The organization chart on page 22 shows graphically how the departments of the commission function.

The original eighteen millions were exhausted by January, 1917. The funds from the new bond issue could not be available under the act until after the beginning of the fiscal year, July, 1917.

At a conference in January, 1917, participated in by all of the State officials concerned, a unanimous decision was reached that the highway work should proceed during the interim, that its cost would be defrayed by borrowing from the Motor Vehicle Fund, and that the State itself would guarantee the sale of not less than three millions of highway bonds when their advertisement and sale should be legal under the act.

The first bond issue of $18,000,000 bearing four per cent interest was hard to market and of the total but $4,280,000 were sold publicly. The remainder, $13,720,000, was taken by various counties.

The second issue of $15,000,000 bearing interest at four and one-half per cent seemed to find a ready market except when the Federal Capital Issues Committee was in operation.

The third issue of $40,000,000, bearing interest at four and one-half per cent, has been difficult to market. The people in the November, 1920, elections increased the interest rate.

Federal Aid Roads

In 1916 Congress passed the Bankhead Act by which the United States co-operates with the several States in highway construction. The law was construed at first somewhat narrowly relative to the type of road which might receive aid from the government. Unless the road was used in the carriage of United States mail, it received little help. It is now understood that almost any main road, over which the mails are likely to go, will receive consideration.

Of the total sum appropriated by this act, California is entitled to the following amounts:*

Fiscal year ending June 30, 1917	$ 151,063.92
Fiscal year ending June 30, 1918	302,127.84
Fiscal year ending June 30, 1919	456,167.32
Fiscal year ending June 30, 1920	609,699.32
Fiscal year ending June 30, 1921 (Estimate)	755,000.00
Total	$2,274,058.40

To June 30, 1920, the State had received $568,000 from the Federal Government, and in the two months following received $389,000.

In addition to the post road feature of the Bankhead Act, the law provides for another class of co-operative work in the national forests. Under Section 8 of this law, California is entitled to approximately $140,000 per year for ten years, beginning June 30, 1916.

An important road which may benefit by the national forest co-operative money is in Mariposa County extending to El Portal, the gateway to Yosemite Valley. Work has also been started for opening the Angeles Forest Reserve under this co-operative act.

State Roads

The Legislature previous to 1917 passed each year special appropriations for the construction or improvement of roads, chiefly in the mountainous counties.

The 1917 Legislature passed an act calling for survey and estimates of cost of such projects as had been presented to it as the committee thought worthy of investigation. These roads were for Southern California as follows:

*From 1st Biennial Report.

A highway beginning at or near Oxnard in Ventura County, California, and extending to a point near San Juan in Orange County, California; and

A highway from the western boundary of Kern County, California, to the State highway near Santa Maria, Santa Barbara County, California.

In August of 1917 the State Engineer passed to the Commission the jurisdiction formerly held by him over the special appropriation roads and they have been cared for since by allotments from the State Motor Vehicle Fund. The roads under this caption of interest to Southern California are as follows:

Mono County—

Routes 13 and 23—Sonora Pass to Bridgeport	34.0	miles
Route 40—Mono Lake Basin	12.3	"
Route 40—Tioga Pass to Mono Lake Basin River	1.0	"
Route 23—Alpine County line to Little Antelope Valley	9.4	"
Route 23—Little Antelope Valley to junction Sonora-Mono road	17.0	"
Total	73.7	"

In San Bernardino County—

Route 43—End of county pavement to most easterly point of Great Bear Lake, approximately 50 miles.

Practically all of these mountain roads are unpaved.

Three-Million-Dollar Laterals

The second State Highways Act of 1915 set aside the sum of three million dollars for the construction of extensions from the trunk lines to various points in the State. These in Southern California are as follows:

An extension connecting the San Joaquin Valley trunk line in Tulare County with the coast trunk line in Monterey County by the continuation of the lateral between the cities of Visalia and Hanford through Coalinga:

An extension connecting the San Joaquin Valley trunk line at or near Bakersfield with the coast trunk line in San Luis Obispo County, through Cholame Pass:

An extension of the San Bernardino County State highway lateral to Barstow in San Bernardino County:

An extension connecting Antelope Valley, in the County of Los Angeles, with the City of Los Angeles:

An extension of the San Bernardino County State highway lateral to the Arizona State line near the town of Yuma, Arizona, via the cities of Brawley and El Centro, in Imperial County.

The act provides that the expense of acquisition, construction and improvement of the extensions enumerated and the acquisition of rights of way therefor shall be partly borne by the counties in which such extensions lie, the extent and character of such division of expenses between the State and county shall rest for final determination with the State Department of Engineering. These several extensions were included in the second bond issue without knowledge of cost, there being no surveys. As per the First Biennial Report of the California Highway Commission the estimated total cost for these extensions in 1917 was $8,963,675. Since there were $3,000,000 provided for these extensions, there remains the sum of $5,963,675 which would have to be paid by the counties. When these estimates were made the Supervisors of the several counties interested were invited to a conference with the Highway Commission. This meeting occurred in September, 1917. It was agreed that the roads should be of permanent type. The plan of apportionment of funds proposed by the Commission was accepted. The list following shows the schedule for Southern California projects to be paid for by the State:

Coalinga Extension	$ 502,860.00
Cholame Pass	448,320.00
San Bernardino to Barstow	178,770.00
San Bernardino to Yuma	756,510.00
Total	$1,886,460.00

The remainder of $3,750,244 was estimated as the counties' share. The Antelope Valley to Los Angeles road is not included in these figures. But little work was done under this act. The bond issue of 1919 in the amount of forty million dollars further provided for the construction of these extensions by the State alone.

The Vehicle Act and Maintenance

State highway maintenance work is financed wholly by the motor vehicle fund which is derived from the fees paid annually by motor vehicle owners and operators into the State treasury.

Under the present law (Vehicle Act of 1915, amended 1917, Chapter 218), after deducting from the total receipts of the Motor Vehicle Department the operating expenses of that department, the balance remaining is divided into two equal parts, one part going to the State Motor Vehicle Fund for use in maintaining the State highways, the other part being paid to the several counties of the State for their use in construction or maintenance of roads. The commission claims that their portion for State highway maintenance is not sufficient.

The Commission states that in general the permissible loads which may be legally carried are reasonable, and that the difficulty is in the non-observance of the rules prescribed by the act and the inability or negligence of the police authorities in their enforcement.**

The Commission believes that until inspectors are appointed by the State to enforce the law, the highways are bound to suffer from overloading.

Right of Way*

By a provision of the Act of 1910, which created the California Highway Commission and provided for the construction of a system of highways, it was required that all right-of-way upon which State highways were built should first be deeded to the State of California. Through an arrangement with the Supervisors of the various counties, it was agreed to secure at county expense or otherwise all necessary right-of-way and to make transfer of same from private owner, or county, to the State. The width of these rights of way is generally sixty feet.

Type of Road (Page 54, 1918 Report, C. H. C.)

At the outset it was determined by the Commission to construct concrete roads. In 1893 New York had built a short length of concrete pavement and Ohio did the same in 1894. Wayne County, Michigan, in 1909, started building four-inch concrete roads. These Michigan roads were well constructed and gave good service for a short period. This was about the only precedent that the California Commission had.†

Width (Page 54, 1918 Report, C. H. C.)

A width of fifteen feet was adopted by the Commission for standard pavements. It was the intention to later widen the roads by building oil, macadam or concrete shoulders.

Thickness (Page 54, 1918 Report, C. H. C.)

A four-inch thickness of slab was adopted. It was claimed that owing to the lack of frost and the general character of the soil over which roads were to be built that this thickness would be ample. It was the intention of the Commission, as occasion demanded, to re-

**(First Biennial Report, Page 31.)
*(From Act and Page 113, First Biennial Report.)
†Blanchard's Highway Engineers' Handbook.

Reinforced concrete bridge over Pine Creek, San Diego County.

Underhead crossing with S. D. & A. Ry. near Coyote Wells, Imperial County.

surface these roads. Because a large percentage of the present four-inch highways have failed, the Commission in October, 1920, adopted a uniform thickness of five inches reinforced.

Subgrades (Standard Specifications Cal. Highway Commission)

The specifications for preparation of subgrade required that all fills should be brought up in layers and properly compacted to a uniform width of twenty-four feet. Cuts were taken out to a width of twenty-one feet. Before placing pavement all subgrade was to be cultivated and wet down, after which it was to be thoroughly compacted over the full width of twenty-four or twenty-one feet, as the case might be, by a roller weighing not less than two hundred pounds per inch width of tire. Where unsuitable material was encountered in the subgrade it was to be removed. This method of preparing subgrade is the one used today.

Drainage

Drain tile has been used in some sections particularly on the Ridge Route and in San Diego County, Section 2-D. Rock drain ditches have been used in many cuts along the coast line.

Bridges (Pages 34 and 113, First Biennial Report, C. H. C.)

Most of the large bridges on the State highways have been paid for by the counties in which they are located, and estimating roughly it is conservative to say that not less than $4,500,000 have been spent by the counties in this manner, and $2,500,000 by the State.

The plans for these bridges in nearly all cases were either made or checked by the Commission's engineers.

After their completion and acceptance these bridges became a part of the State highway system and are maintained by it.

The elimination of railroad crossings is of great importance, and to this end a number of overhead crossings and subways have been installed at the joint cost of the State and counties, and the railroad companies.

California has no statutes fixing a basis for the division of costs in cases of separation of grades as between the railroads and the State or counties. This is left to the determination of the Railroad Commission of California.*

The railroad companies have co-operated with the California Highway Commission in joint enterprises for the mutual protection of the railroads and the traveling public. (Page 34, 1918 Report, C. H. C.)

Appropriations Under the Acts of Legislature

The method of payment of the principal and interest of the various bond issues is set forth in the Acts providing for them.

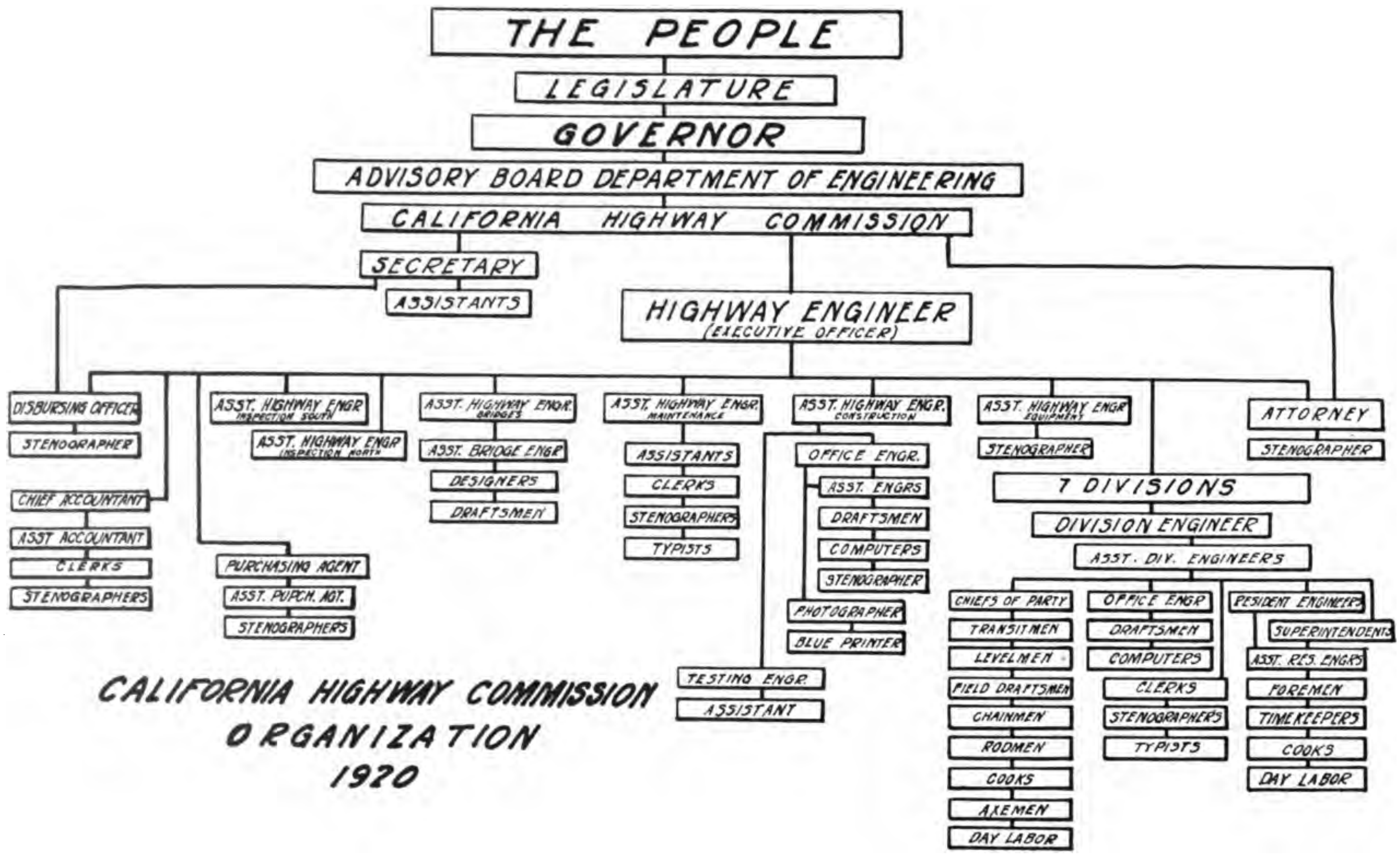
The State Highways Act of 1909 (Stats. 1909, Chapter 383, Page 647) provided for the issuance of bonds in the sum of $18,000,000. This issue consisted of 18,000 bonds of the par value of $1,000 each. They bear date of July 3, 1911. The rate of interest is four per cent per annum from the date of issuance. The principal of these bonds was payable as follows:

The first four hundred (400) on July 3, 1917 and four hundred (400) more were payable on the 3rd day of July of each and every year thereafter until 1961. The interest accruing on all bonds sold is made payable semi-annually on the third days of January and July of each year.

The State Highways Act of 1915 (Stats. 1915, Chapter 404, Page 650) created a bond issue of $15,000,000 for the completion of the original system and the addition of certain laterals. These bonds were also of the par value of $1,000 each and were numbered from one (1) to fifteen thousand (15,000) inclusive. They bear date of July 3, 1917. The interest is four and one-half per cent.

*(Page 35, First Biennial Report, C. H. C.)

Diagram No. 1



CALIFORNIA HIGHWAY COMMISSION
ORGANIZATION
1920

The first three hundred seventy-five (375) of these bonds will be payable July 3, 1923. Three hundred and seventy-five (375) more will be payable on July 3rd of each year thereafter until the final payment in 1962. Interest payments are to be made semi-annually.

The Constitutional Amendment adopted July 1, 1919, provided for a third State Highway Bond Issue in the sum of $40,000,000. These consist of forty thousand (40,000) bonds of the par value of $1,000 each. The interest rate is four and one-half per cent, payable on January 3rd and July 3rd of each year. The bonds become due and payable in parcels of one thousand (1,000) commencing July 3, 1926 and ending July 3, 1965.

Routes and Mileage

The following routes and mileage of State highways, under the three bond issues, were proposed to the voters:

PROPOSED STATE HIGHWAYS UNDER
FIRST BOND ISSUE

Rt.	From	To	Mileage
1	San Francisco	Crescent City	371.2
2	San Francisco	San Diego	481.8
3	Sacramento	Oregon Line	291.3
4	Sacramento	Los Angeles	359.0
5	Stockton	Santa Cruz via Oakland	116.9
6	Sacramento	Woodland Junction	14.3
7	Tehama Junction	Benicia	142.7
8	Ignacio	Cordelia via Napa	38.6
9	San Fernando	San Bernardino	53.5
10	Goshen (4)	Hanford	13.2
11	Sacramento	Placerville	46.5
12	San Diego	El Centro	127.5
13	Salida	Sonora	49.2
14	Albany	Martinez	20.6
15	Williams	Colusa	8.7
16	Hopland	Lakeport	19.3
17	Roseville	Nevada City	33.4
18	Merced	Mariposa	39.2
19	Rt. 9 West of Claremont	Riverside	17.7
20	Redding	Weaverville	50.0
21	Rt. 3 near Richvale	Oroville	7.0
22	San Juan Bautista	Hollister	7.1
23	Saugus	Bridgeport	337.5
24	Rt. 4 near Lodi	San Andreas	36.6
25	Nevada City	Downieville	47.0
28	Redding	Alturas	151.1
29	Red Bluff	Susanville	100.0
30	Oroville	Quincy	67.0*
34	Rt. 4 near Arno	Jackson	34.4
	Total		3082.3

PROPOSED STATE HIGHWAYS UNDER
SECOND BOND ISSUE

Rt.	From	To	Mileage
10	Hanford	San Lucas	98.25
18	Mariposa	El Portal	32.60
20	Douglas City	Rt. 1 Arcata	102.00
26–27	San Bernardino	Yuma via El Centro	195.86
31	San Bernardino	Barstow	76.33
32	Rt. 4 near Califa	Gilroy	83.45
33	Rt. 4 near Bakersfield	Paso Robles	91.22
	Total		679.71

*Route 30 has been abandoned, and Route 21 extended to cover approximately same mileage.

THIRD BOND ISSUE

58	Mojave	Needles (via Barstow)	255.
60	Oxnard	San Juan Capistrano	86.
57	Santa Maria	Freemans via Bakersfield	202.
55	San Francisco	Santa Cruz	67.
53	Rio Vista	Fairfield	24.
*1–37	Auburn	Verdi	95.
15	Ukiah	Emigrant Gap	212.
*2–38	Truckee	Tahoe City	
1	Crescent City	Oregon Line	40.
51	Santa Rosa	Shellville	24.
63	Big Pine	Oasis	40.
*3–11	Placerville	Sportsman's Hall	10.
21	Oroville	Quincy	27.
41	Gen. Grant National Park	Kings River Canyon	20.
49	Calistoga	Lower Lake	32.
64	Mecca	Blythe	100.
50	Rumsey	Lower Lake	35.
62	Azusa	Pine Flats in San Gabriel Canyon	10.
61	La Canada	Mt. Wilson Road via Arroyo Seco	10.
59	Lancaster	Baileys	40.
48	McDonalds	Mouth of Navarro River	47.
56	Carmel	San Simeon	97.
46	Klamath River Bridge (Rt. 3)	Route 1 near Mouth of Klamath River	177.
29	Susanville	Nevada State Line	53.
22	Pacheco Pass Road	Into Hollister	8.
10	Visalia	Sequoia National Park	36.
43	Deep Creek	Metcalf Creek	14.
47	Orland	Chico	20.
52	Tiburon	Alto	5.
54	Near Michigan Bar	Drytown	12.
	Total		1798.

*1 95 miles maintained under Special Appropriation Roads.
*2 15 miles maintained under Special Appropriation Roads.
*3 10 miles maintained under Special Appropriation Roads.

STANDARD SECTIONS OF CALIFORNIA ROADS

Pages 27 to 30 show typical sections that were adopted from time to time by the California Highway Commission for the building of the State highways.

There is also shown on Page 30 typical cross section of the pavement being built by the State of Washington.

Table No. 1 (Page 31) gives the width and thickness of various State pavements. It is difficult to make comparisons because the different States have various standard widths and also widths of pavements used for special localities. The standard width of the California pavements is 15 feet on trunk roads with increased widths on mountain grades and approaching cities. Some 8-foot widths have also been built.

Out of the thirty-five States listed, three are shown as building narrower pavements. They are Delaware (14 feet to 18 feet), Mississippi (9 feet to 18 feet) and Nevada (9 feet to 16 feet). Maryland and Texas have a fifteen to eighteen-foot pavement. The remaining thirty States build wider pavements than California.

California has recently increased the standard thickness of its slab from 4 to 5 inches and reinforced it. No other State is reported as building a standard pavement as thin as either four or five inches with the exception of Georgia which has a five-inch thickness of reinforced slab similar to California. All of the rest build thicker pavements. Reinforcing

3-9 Longitudinal crack near San Onofre, San Diego County. Pavements in this condition are classed "poor" and require reconstruction.

3-10 Longitudinal crack near San Onofre, San Diego County.

does not materially add to the strength of the pavements. It does, however, hold together the fragments when it is broken.

The mixture now used in California is one of cement, two of sand and four of stone. One (Mississippi) of the thirty-five States uses a leaner mixture. Nine others used a similar mixture to California. The remaining twenty-five States use richer mixtures.

Table No. 2 (Page 32) shows details in which different States build their pavements as to reinforcement, joints, method of curing, etc. Most of them require a longer period of curing than California. Of the forty-eight States shown in the table, thirty-five require expansion joints in the construction of the concrete slab. The others either do not require it or do not specify. The expansion joints in roads in Washington and Oregon are placed usually thirty feet apart and filled with elastite. This filler is one-quarter of an inch thick when placed in the summer and thicker when placed in the cooler months. It gives a finished appearance to the work.

In making the concrete in Washington, the different aggregates are graded in size and usually washed.

In the very important feature of trueness of surface of the pavement when finished, California requirements are as exacting as those used in most other States. It allows for a variation of a quarter of an inch in five feet. New Jersey allows a quarter of an inch in ten feet, as does Pennsylvania. A smooth surface avoids road shock and thus extends the life of the pavement. The most exacting results should be insisted on in this particular.

The following data relates to Southern California County Concrete Highways in 1920:

Counties	Width Feet	Thickness Inches	Mix
San Diego	18	5	1-2-4
Imperial	16	6–5–6	1-2-4
Riverside	16	4	1-2-4
San Bernardino	16	4	1-2-4
Los Angeles	18-24	5 to 8	1-2-4
Ventura	16	4	1-2-4
Santa Barbara	16	4 to 6	1-2-4
Kern	18	6	1-2-4
San Luis Obispo	15-18	4 to 5	1-2-4
Orange	18-20	4	
Tulare	16	5	1-3-6(Trunk lines)
Tulare	15	4	1-2-4(Laterals)

Diagram No. 2

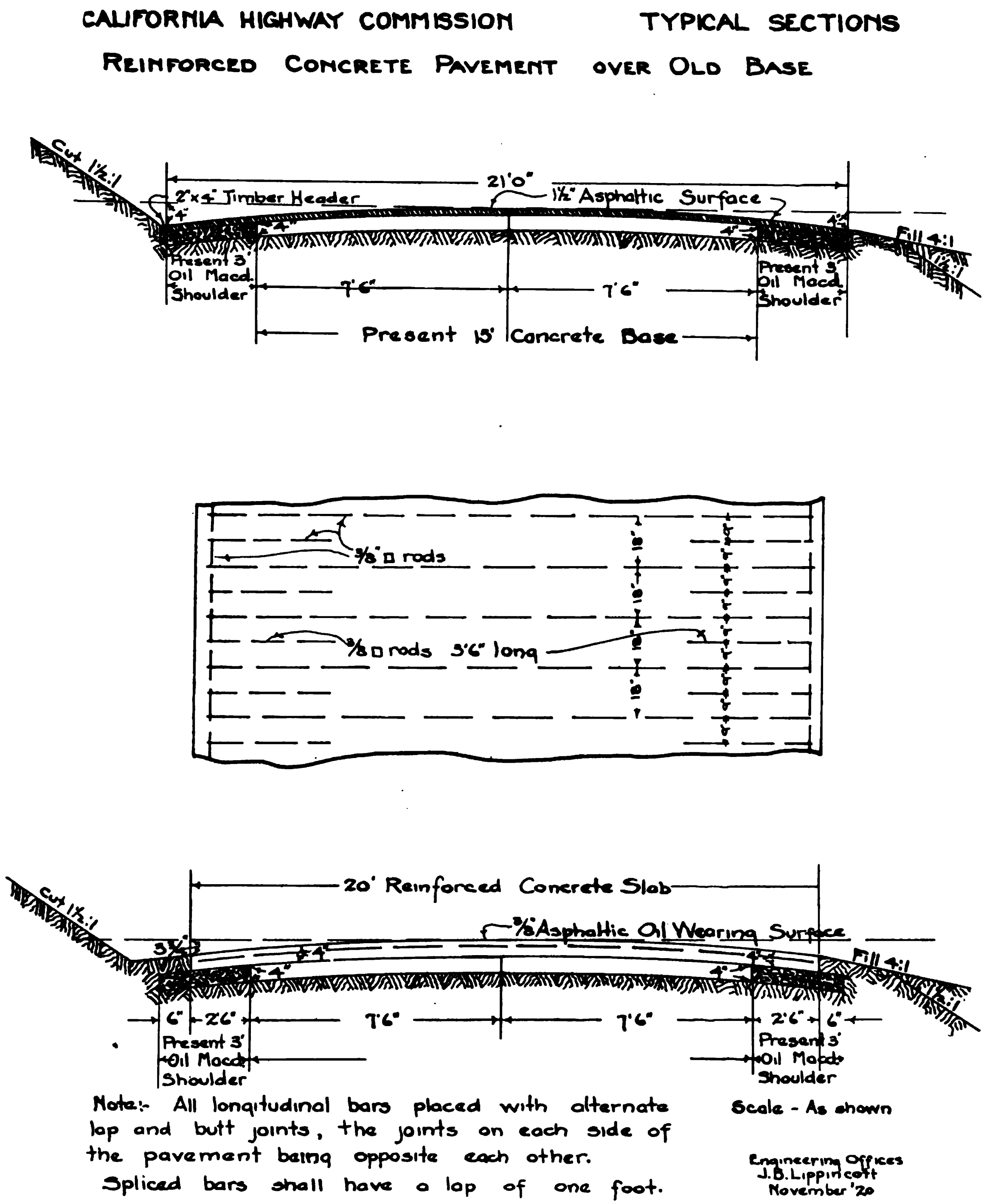
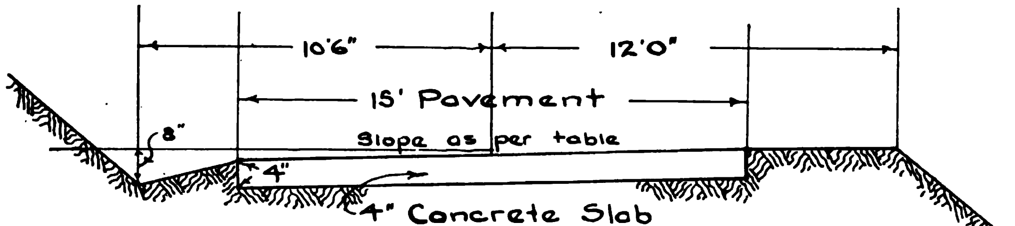

CALIFORNIA HIGHWAY COMMISSION
TYPICAL SECTIONS
REINFORCED CONCRETE PAVEMENT OVER OLD BASE
Cut 1½:1
21'0"
2"x4" Timber Header
1½" Asphaltic Surface
Fill 4:1
Present 3' Oil Macd. Shoulder
7'6"
7'6"
Present 3' Oil Macd. Shoulder
Present 15' Concrete Base
⅜" □ rods
⅜" □ rods 5'6" long
18"
20' Reinforced Concrete Slab
⅜" Asphaltic Oil Wearing Surface
Cut 1½:1
Fill 4:1
6"
2'6"
7'6"
7'6"
2'6"
6"
Present 3' Oil Macd. Shoulder
Present 3' Oil Macd. Shoulder
Note:- All longitudinal bars placed with alternate lap and butt joints, the joints on each side of the pavement being opposite each other.
Spliced bars shall have a lap of one foot.
Scale - As shown
Engineering Offices
J.B. Lippincott
November '20

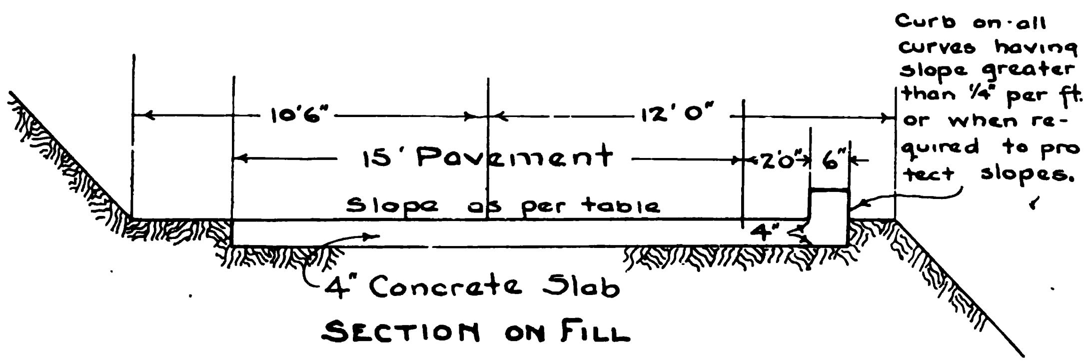
Diagram No. 2-A

CALIFORNIA HIGHWAY COMMISSION TYPICAL SECTIONS



SECTION ON CUT

Use on Curves under 300' radius concave to cut



SECTION ON FILL

Use on Curves under 300 radius concave to fill

TABLE OF CROSS SLOPES

Radius of Curve	Slope
50' to 75'	¾" per ft
75' to 100'	½" " "
100' to 150'	⅜" " "
150 to 225'	¼" " "
225' to 300'	⅛" " "

Scale - As shown

Engineering Offices
J.B. Lippincott
November '20

Diagram No. 2-B

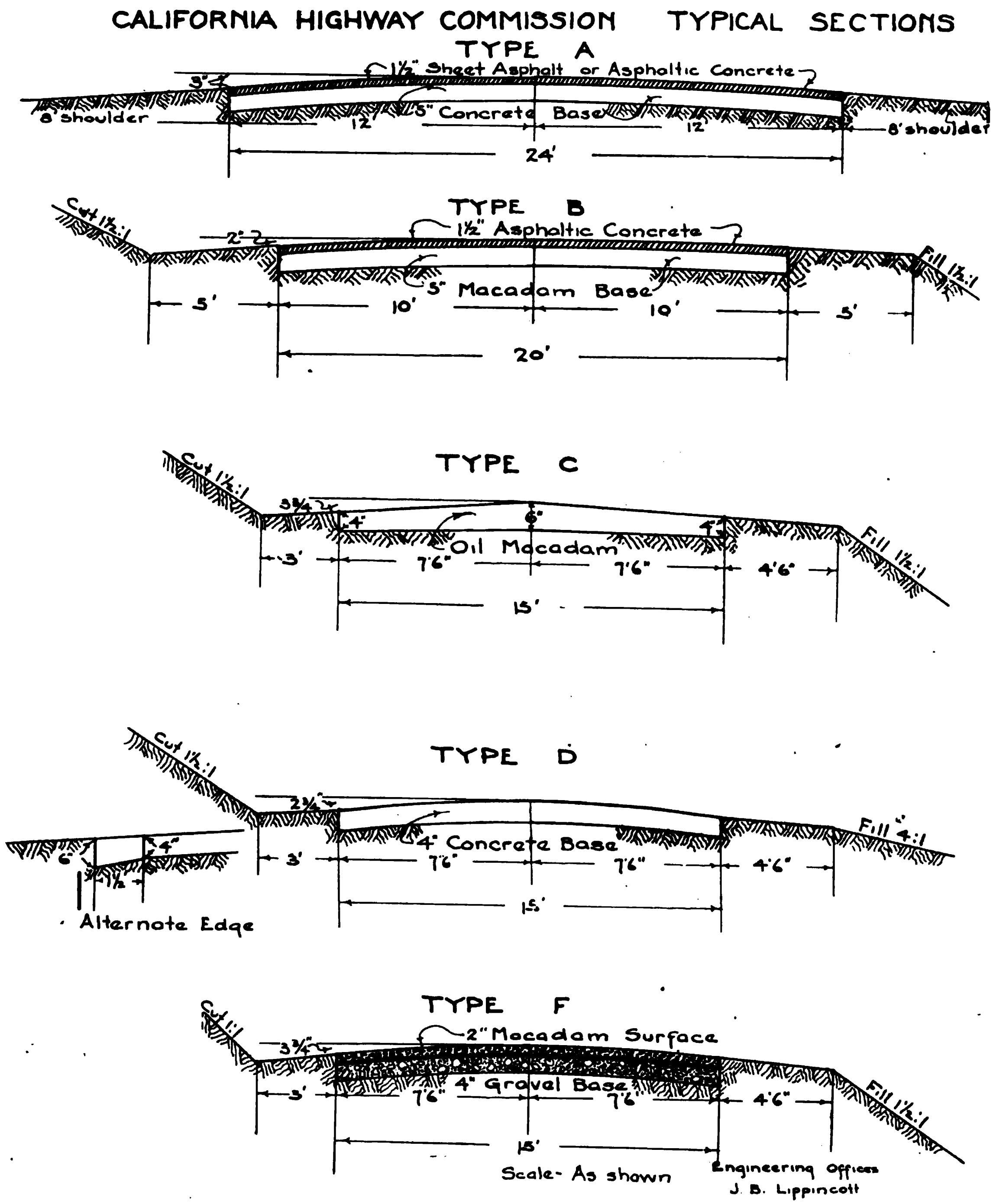
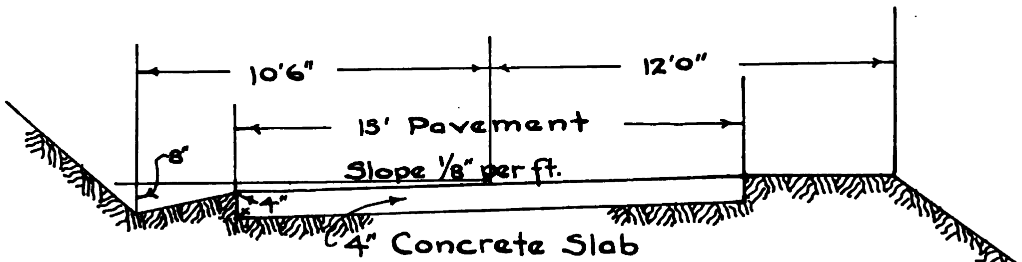


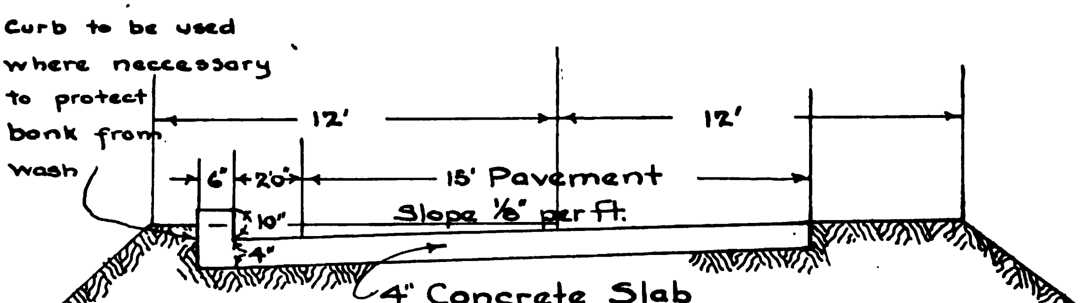
Diagram No. 3

CALIFORNIA HIGHWAY COMMISSION TYPICAL SECTIONS



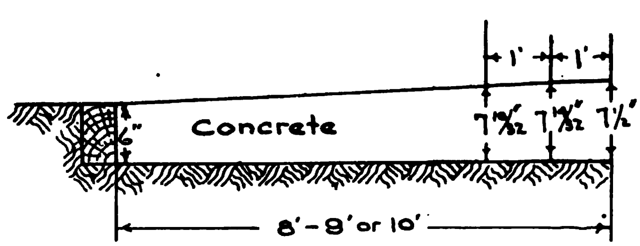
SIDE HILL SECTION

Use on tangents & curves over 300' radius



SECTION OVER FILLS

Use on tangents & curves over 300' radius



HALF SECTION ONE COURSE CONCRETE ROAD
AS USED IN THE **STATE** OF **WASHINGTON**

Scale - As shown

Engineering Offices
J. B. Lippincott
November '20

TABLE NO. 1

TABLE SHOWING WIDTH AND THICKNESS OF CONCRETE PAVEMENTS
STATE HIGHWAY AWARDS FOR 1920

State	Width Feet	Thickness Inches	Proportions
California	15-20	4-6	1:2:4
Colorado	18	6-7½	1:2:3
Connecticut	16-20	6-8	1:2:4
Delaware	14-18	5-7 & 6-8	1:2:4-1/10 Hyd. Lime
Georgia	16-18	6 uniform	1:2:4
Idaho	18	5½-6½	1:2:3
Illinois	16-20	8 uniform	1:2:3½
Indiana	18	6-8	1:1½:3
Iowa	18	7-8	1:2:3½
Kansas	18	6-8	1:2:3½
Maine	16	6-8 & 7-9 reinf.	1:2:3½
Maryland	15-18	5-7 & 6-8	1:1½:3
Massachusetts	18	5-7¼	1:2:4:8/100 Hyd. Lime
Michigan	16-20	6-8	1:1½:3
Minnesota	.....	7-8	1:2:3½
Mississippi	9-18	6 uniform	1:2:3
Missouri	18	6-8 & 7-9	1:2:3
Nevada	9-16	6 uniform	1:2:4
New Jersey	18-20	6-8 to 10-12½	1:2:3
New Mexico	16	5-7	1:2:3
New York	16-20	5-6 & 6-8 reinf.	1:2:4
North Carolina	18	7 uniform	1:1½:3
Ohio	10-20	6-8 & 8-10	1:1½:3
Oklahoma	18	7 uniform	1:2:3
Oregon	18	6-7	1:1½:3
Pennsylvania	16-18	5-7 & 6-8	1:2:3
Rhode Island	18	6-8	1-2:3
South Carolina	16-18	6	1:2:4
Tennessee	16-18	6-8	1:2:4
Texas	15-18	6-8 uniform	1:2:3½
Utah	18	6-8	1:1¾:3½
Virginia	16-18	6-8	1:2:4
Washington	18-20	6-7½	1:2:3
West Virginia	16	6-8	1:2:3
Wisconsin	18	7-8	1:2:3½

Recent California Specifications: Minimum of 5-inch reinforced longitudinally with ½-inch deformed bars in center of slab depth and 2-inch from edge, lapped 12-inch for bond and at intervals of not more than 30 feet—butted and not lapped. Reinforced transversely with ⅜-inch deformed bars on 18-inch centers.

Table No. 2

SUMMARY OF STATE HIGHWAY DEPARTMENT SPECIFICATIONS FOR CONCRETE ROADS

STATE	DATE	PROPORTION	Time of Mix Minutes	Mixer Water Meas. Device	REINFORCEMENT Specified	REINFORCEMENT Mesh Lb. per 100 Sq. Ft.	REINFORCEMENT Bars Specified	Expansion Joints	Trueness of Surface Allowance of Variation Inches to Ft.	CURING Canvas Cover	CURING Wet Earth	CURING Ponding	CURING Kept Covered Min. Days	CURING Cls'd to Traffic Min. Days
Alabama	1920	1-2-3	1	Yes				Yes		Yes	Yes		18	21
Arizona	1920	1-2-3½	1	"					¼	"	"	Yes	20-14	30
Arkansas	1919	1-2-3	1	"				Yes		"	"		7	14
California	1919	1-2-4	1		See Plans		Yes		¼-5		"	Yes	10	
Colorado	1919	1-2-3	1½		When Used	25		Yes	¼		"	"	10	14
Connecticut	1920	1-2-4	1½	Yes	When Used	25		"		Yes	"		8	11
Delaware	1920	1-2-4	1½	"					1/16-1	"	"	Yes	14	30
Florida	1919	T-1-2-3 B-1-3-6	1	Yes				Yes		Yes	Yes		18	21
Georgia	1920	1-2-4	1	"				"			"	Yes	18	21
Idaho	1919	1-2-3	1	"	See Plans					Yes	"		10	14
Illinois	1920	1-2-3½	1						¼-10	"	"	Yes	20-14	30
Indiana	1919	1-1½-3	1	Yes	When Used	40			¼	"	"	"	18-15	21
Iowa	1920	1-2-3½	1	"	See Plans		Yes		¼-10	"	"	"	14	28
Kansas	1920	1-2-3½	1		When Used	45		Yes	¼	"	"	"	20-14	30
Kentucky	1918	1-2-3	1½	Yes	See Plans			"	½-10:¼-3	"	"		15	18
Louisiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maine	1920	1-2-3½	1	Yes				Yes	¼-5	Yes	Yes		18	21
Maryland	1919	G.1-1½-3 S.1-2-4	1	"	When Used	22-25				"	"		18	21
Massachusetts	1920	1-2-4	1½	"						"	"		11	14
Michigan	1918	G.1-1½-3 S.1-1¾-3	1					Yes	½-10:¼-3	"	"		14	14
Minnesota	1920	1-2-4 1-2-3½	1		Yes	30	Yes			"	"	Yes	14	21
Mississippi	1920	1-2-3	1	Yes				Yes		"	"	"	14	21
Missouri	1919	1-2-3	1		When Used	25		"	¼	"	"		14	21
Montana	1920	1-2-3	1		See Plans			"	¼-10	"	"	Yes	20	30
Nebraska	1920	1-3, 1-2-3	1		See Plans			"		"	"		10	14
Nevada	1919	1-2-4	1	Yes				"				Yes	12	21
New Hampshire	1918	1-2-3	1½	"	When Used	25		"		Yes	Yes		18	21
New Jersey	1920	1-1½-3	1½	"	See Plans			"	¼-10	"	Wet	Straw	10	14
New Mexico	1919	1-2-3	1½	"	When Used	25		"		"	Yes		18	21
New York	1920	1-2-4	1		When Used	25		"	½-10		"	Yes	14	14
North Carolina	1918	1-1½-3	1½	Yes	When Used	25		"		Yes	"		16	21
North Dakota	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ohio	1919	1-1½-3	1	Yes	When Used	28		Yes	½-10	Yes	Yes		10	21
Oklahoma	1918	1-2-3	1½	"	When Used	25		"		"	"		18	18
Oregon	1919	1-1½-3	1					"			"		21	21
Pennsylvania	1920	1-2-3	1¼	Yes	When Used	25	Yes	"	¼-10	Yes	"		18	21
Rhode Island	1920	1-2-3	1	"				"		"	"		18	21
South Carolina	1919	1-2-4	1	"	When Used	25		"		"	"		18	21
South Dakota	1920	1-2-3	1	"				"		"	"		18	21
Tennessee	1920	1-2-4	1½	"					¼-8	"	"		14	21
Texas	1920	1-2-3½	1	"	When Used	25		"		"	"	Yes	14	20
Utah	1920	1-1¾-3½	1	"	Yes	See Plans	Yes	"	¼	"		"	14	20
Vermont	1920	1-2-3	1	"				"			Yes		18	21
Virginia	1920	1-2-4	1	"	When Used	40	"	"	¼	Yes	"		18	21
Washington	1920	1-2-3	1	"	When Used	28		"		"	"	Yes	14-10	30
West Virginia	1918	1-2-3	1	"	See Plans	25	Yes	"			"		10	14
Wisconsin	1919	1-2-3½	1	"	See Plans			"	¼	Yes	"		18	21
Wyoming	1919	1-2-3	1					"	¼	"	"		10	14

18-5 Broken down edge of pavement mile 1.55 north of Sandberg, "Ridge Route," Los Angeles County.

Excessive transverse cracking near Grapevine Station south of Bakersfield, Kern County.

MILES OF ROADS BUILT

The public has not been fully informed that adequate and permanent roads would cost more than the estimates and bond issues indicated. This has resulted in the building of roads that are dangerously narrow and too frail and the leaving off of the shoulders which are a necessary part of the permanent construction of the highways.

Out of the first bond issue 1,044 miles of State roads were proposed for Southern California. Of these but 655 miles were constructed, inclusive of 65 miles that were built by the counties. Fifty-six per cent of the program under this bond issue, therefore, has been completed in Southern California.

Out of the second bond issue 370 miles of roads in addition to the first 1,044 miles were proposed to be built in Southern California. Considering these 370 miles of new roads, but 62 miles have been built to date in Southern California of which 33 miles were constructed by the counties. The exact proportion of the second bond issue that has been expended is, at this writing, not known to us but it is understood that the greater portion of it has been spent. Less than six per cent of this program under the second bond issue has been carried out.

Probably funds from the second bond issue have been used in part for the construction of trunk roads specified in the first bond issue. Of the $15,000,000 provided for in the second bond issue, $3,000,000 were made available for co-operative work with the counties for the building of certain specified laterals. Of the $15,000,000 in bonds, $13,000,000 of this issue have been sold, but there has been charged against this issue $13,784,000, thus necessitating borrowing from some other fund. The third bond issue provides for the building of these laterals exclusively at the expense of the State. A list of roads proposed under the third bond issue is given on Page 23.

According to lists given on Pages 23 and 24 that have been furnished by the State Highway Commission, there were to be constructed in Southern California from the first and second bond issues, including the laterals, 1,414 miles of highways. From these two issues to date there have been built by the Commission 619 miles of road or forty-three per cent (43%) of the program, or 709 miles inclusive of sections of road built by various counties and incorporated in the highway system.

The details of these programs are given on pages 35 and 36.

The total mileage proposed to be built by the first and second issues for the entire State was 3,762. Practically no roads have yet been built with the third bond issue. The total actual mileage built in the State system to July, 1920, excluding roads acquired from the counties and mountain unpaved roads, is:*

Concrete base	1,231.63	miles
Asphalt on concrete base	52.36	"
Macadam	32.04	"
Asphalt on Macadam	16.53	"
	1,332.56	miles

*Compiled from "Tabulations of average life of State highways," furnished by California Highway Commission.

Statement of work done and to be done on the various State highway routes as proposed under first and second bond issues in Southern California to July 1, 1920:*

FIRST BOND ISSUE

Route No. 2—South line Monterey County to San Diego:		
Total length by sections		323.74 miles
Total complete by State	275.93	
Total complete by counties	14.13	
Total to be completed	33.68	
Total	323.74	
Route No. 4—South line Fresno County to north city limits of Los Angeles:		
Total length by sections		185.09 miles
Total built by State	171.93	
Total built by counties	6.43	
Total to be completed	6.73	
Total	185.09	
Route No. 9—San Fernando to San Bernardino:		
Total length by sections		53.48 miles
Built by State	34.18	
Built by counties	18.80	
To be built	.50	
Total	53.48	
Route No. 12—San Diego to El Centro:		
Total length by sections		113.77 miles
Total built by State	55.20	
To be built	58.57	
Total	113.77	
Route No. 19—From Route No. 9 near Claremont to Riverside via Pomona:		
Total length by sections		17.74 miles
Total built by State	16.14	
Total built by county	1.60	
Total	17.74	
Route No. 23—Saugus to Bridgeport:		
Total length by sections		337.50 miles
Total built by State	22.86	
Total built by counties	24.43	
Total to be built	290.21	
Total	337.50	
Route No. 10—Visalia to Hanford:		
Total length by sections		13.16 miles
Total built by State	13.16	

Summary under First Bond Issue:

Total built by State	589.40
Total built by counties	65.39
Total to complete	389.69
TOTAL	1,044.48

*From historical data furnished by California Highway Commission.

SECOND BOND ISSUE

Route No. 10—Hanford to San Lucas:

Total length by sections		98.25 miles
Built by State	8.06	
To be completed	90.19	
Total	98.25	

Routes No. 26 and 27—San Bernardino to Yuma:

Total length by sections		195.86 miles
Built by State	21.12	
Built by counties	9.15	
To be completed	165.59	
Total	195.86	

Route No. 31—San Bernardino to Barstow:

Total length by sections		76.33 miles
Built by State	0.00	
Built by counties	23.97	
To be completed	52.36	
Total	76.33	

Summary Under Second Bond Issue:

Total to be built		370.44 miles
Built by State	29.18	
Built by counties	33.12	
To be completed	308.14	
	370.44	

Summary of First and Second Bond Issues:

Total miles proposed		1,414.92
Completed by State	618.58	
Completed by counties	98.51	
To be completed	697.83	
	1,414.92	

APPROXIMATE AVERAGE FIRST COSTS OF HIGHWAYS

In order to make general deductions and conclusions, it was necessary to assemble practically all the data of a physical, historical and financial nature together in one set of tables. This data is the foundation upon which the general conclusions herein are drawn. It is of too elaborate and extensive a nature to publish in this report. It is placed with many other details in the archives of the Automobile Club of Southern California.

These tables classify the road work by counties, years built, routes, lengths, dimensions of slab, sub-base condition, service, costs, reconstruction charges, past and present conditions, maintenance costs, traffic, and causes of failure. There are 52 columns so grouped. The data presented in these tables has been considered under various subjects separately in this report.

It is difficult and often misleading to make generalized statements as to the relative costs of roads because of the variation of the conditions that enter into such charges; for instance, the length of haul of the concrete aggregates, the quantities of excavation in the road-bed itself, water situation, etc. However, it is desirable to form some idea of the increase in the cost of highway construction, due to advancing figures, during the past seven years in which California roads have been built. Comparisons are only made between roads built on valleys and plains because of wide variation in excavation costs of mountain construction.

The following original costs of building State and county concrete pavements have been obtained for Southern California:

TABLE NO. 3

Built by	Miles	Type*	Year Built	Pavement Cost Per Mile	Total Cost Per Mile‡	Character of Country
State (1)	160.35	4x15 B	1914-1917	$ 8,460	$12,343	Flat
"	126.23	4x15 B	1914-1917	8,502	14,677	Rolling
"	43.75	4x18 B	1914-1917	8,027	10,858	Flat
"	10.00	4x15 B	1914-1917	10,241	19,389	Mountain
"	23.57	4x20 A Reinf.	1918-1919	30,352	51,423	Mountain
"	10.19	4x20 A Reinf.	1920	34,342	47,044	Mountain
"	10.37	5x20 A Reinf.	1920	46,758	....	Mountain
L. A. County (2)	13.20	5x20 B	1916	....	13,700	Flat to Rolling
" "	12.80	5x20 B	1914-1917	....	17,830	Flat
Orange (3)	48.79	4x16 B				
"	75.94	4x18 B	1914-1919	....	9,267	Flat
"	12.51	4x20 B				

*Class A is of 1-2-4 mix. Class B. is of 1-2½-5 mix.
‡Fourteen per cent has been added to Commission's figures for overhead, etc., on State roads only. The overhead for county work is included in totals shown.
(1) Compiled from data furnished by C. H. C.
(2) Compiled from data furnished by L. A. Co.
(3) Compiled from data furnished by Orange Co.

It will be noted that the road with a 4″x18′ concrete pavement appears to cost less than the road with a 4″x15′ concrete pavement, both having the same aggregates. In the early stages of road building costs were not well established and a large number of contractors lost. There were very wide variations in the prices bid. The pavement alone on a 4″x18′ road cost approximately $425.00 per mile less than the pavement on a 4″x15′ road. The haul of materials on the wider pavement generally was less than the haul of materials on the 4″x15′ road.

In comparing the original costs of concrete roads built by the State and several counties, as given in Table No. 3, page 37, it is found that Orange County built 137 miles of road during the years 1914 to 1919 over generally flat country varying the width of road from 16 feet to 20 feet at a total cost per mile of $9,267.00. These roads were 50 per cent surfaced with ⅜-inch oil and screenings. The State built 160 miles of road in Southern California during the years 1914 to 1917 over flat country with a width of pavement of 15 feet and the same thickness of concrete as Orange County at a total cost of $12,343.00 per mile. This figure does not include cost of shoulders. A further comparison shows that the pavement cost alone on the State jobs, for a narrower pavement, was 92 per cent as much as the total costs for pavements, road-bed and openings for Orange County.

Los Angeles County costs fall between the Orange County and State costs. It is interesting to note that 13.20 miles in Mint Canyon, which can be classed as rolling country, cost the county $13,700.00 per mile as compared with the average State cost of $14,677.00 per mile in rolling country in Southern California for the same period, Los Angeles County building a 5-inch thick by 20-feet wide pavement, and the State constructing a pavement 4 inches thick by 15 feet wide without shoulders. The above costs for country-built road include a ⅜-inch oil surfacing but no shoulders, these not being necessary with the 20-foot pavement built.

In Orange County the State built 11.2 miles of 4″x18′ concrete paved road in 1914. The average cost per mile, exclusive of overhead, was $9,567.00. Fourteen per cent has been added to include overhead, making the total cost per mile $10,906.00. The total cost per mile for 67.53 miles of 4″x18′ concrete road built by Orange County in the years 1915, 1916 and 1917 was $9,037.00, including actual overhead and all incidental expenses. Of these State and county roads approximately 50 per cent were surfaced with ⅜-inch oil and screenings.

Table No. 4

TABLE SHOWING CONSTRUCTION AND MAINTENANCE COSTS OF VARIOUS OIL MACADAM HIGHWAYS

COUNTY	NAME OF ROAD	Length	Dimensions	Sq.Yds.	Av. Age	Total Cost Mile	Total Maintenance	Annual Maintenance Per Sq.Yd.	Annual Maintenance Per Yr.Mi.	Traffic Tons 24 Hrs.	REMARKS
Oiled Macadam	**Roads**										
Los Angeles.....	Whittier Road...........=	14.13	6x20	165,792	8.15	15,034	72,551	0.0537	630.	5,900	
" "	Foothill Boulevard.......=	18.80	6x20	220,586	8.00	13,732	44,440	0.0252	295.	2,400	
" "	City Limits to Saugus.....=	6.43	6x20	75,445	8.00	13,506	22,425	0.0371	436.	1,950	Maintenance over Newhall grade heavy
" "	Long Beach Blvd...........	12.47	7x24	175,575	9.33	23,238	63,434	0.0387	545.	5,229	Per cent of pleasure cars high
" "	Harbor Boulevard..........	11.33	7x24	159,526	8.33	26,682	81,576	0.0614	864.	4,828	Per cent of motor trucks high
" "	El Monte-Pomona..........	19.39	7x20	227,509	7.00	19,246	95,621	0.0600	704.	4,540	Considerable adobe soil
" "	Valley Boulevard..........	9.67	7x18	102,115	7.00	13,162	25,372	0.0355	377.	1,655	
" "	Telegraph Laguna Road.....	4.53	6x18	47,837	7.00	9,061	7,551	0.0226	238.	Light	
San Bernardino..	Cajon Pass Road.........*	15.17	4x16	142,396	1.5	....	2,664	0.0124	117.	Light	

Remarks:

=Roads marked thus are now State property and maintenance costs are for entire life of road and includes both State and county expenditure.

*Road now State property. County maintenance not available.

Table No. 4, page 38, shows costs and maintenance of various oiled macadam roads built and partly maintained by several counties. The original cost is generally higher than concrete roads since they are usually thicker and wider.

The following costs apply to typical **Reconstruction** jobs. The California Highway Commission's designation of this class of work is "Resurfacing and Widening" and "New Pavement on top old base." In this report the above items are included in reconstruction or upkeep and are considered as maintenance costs. Twenty per cent has been added to the figures furnished by the State.

Location	Miles	Type	Year Built	Cost per Mile
L. A. 2-A................	1.33	4"x20' A Reinforced Concrete	1919-20	$24,230
L. A. 2-A................	3.90	1½"x21' Topeka Top	1919-20	10,900
L. A. 4-A................	1.00	1½"x15' Willite	1919-20	18,480
L. A. 4-B................	2.74	1¼"x20'	1920	12,800
Imp. 27-A*...............	.91	3-5"x15' Willite		42,059

*The last item in the above is for original Willite pavement laid on the desert east of Holtville, and reflects high material costs as some of the aggregates used were for experimental purposes and hauled long distances.

With a given width of pavement the cost per mile of construction for a concrete slab is not in direct proportion to its thickness. The preparation of the road-bed and the subgrade is the same. The cost of buying and placing the equipment for the construction work is also much the same. Surveys, supervision and overhead are practically alike. The increased cost would vary rather directly with the volume of the materials used in the slab. Satisfactory data on these comparative costs for California roads is not available. Table No. 3, page 37, however shows that 160.35 miles of pavement, 4 inches thick and 15 feet wide, were built by the State in flat country in Southern California at a cost for grading and paving of $12,343.00 per mile between the years 1914 and 1917. Another item shows that 43.75 miles of pavement, 4 inches thick and **18 feet** wide, were built by the State during the same period in flat country in Southern California at a cost for grading and pavement of $10,858.00 per mile. Orange County built 137 miles of pavement between the years 1914 and 1919, in flat country, 49 miles of which was 16 feet wide, 76 miles 18 feet wide, and 13 miles 20 feet wide, all 4 inches thick, for $9,267.00 per mile. Los Angeles County built 13.2 miles of pavement, 5 inches thick and 20 feet wide, in 1916, in flat to rolling country, for $13,700.00 per mile, and again on another job 12.8 miles of the same dimensions, between the years 1914 and 1917, in flat country, for $17,820.00 per mile, these figures all being for both grading and pavement.

Table No. 3 shows that on State work in flat country during the same years there is little difference between the cost of pavement 15 feet wide and 18 feet wide, both having the same thickness.

The following information has been obtained on this subject for certain roads in the State of Washington: On April 22, 1920, three bids were offered in Pierce County, Washington, upon concrete pavement, both 6 and 7 inches thick. They were as follows:

6-inch pavement, per square yard..................	$1.88	$2.20	$2.30
7-inch pavement, per square yard..................	2.01	2.40	2.41

On another job in the same county on November 28, 1919, the following bids were received:

6-inch pavement, per square yard..........	$1.87	$1.90	$2.10	$2.30
7-inch pavement, per square yard..........	2.00	1.90	2.20	2.41

In the city of Seattle three bids were received on pavements 7 and 8 inches thick, as follows:

7-inch pavement, per square yard	$2.25	$2.34	$2.40
8-inch pavement, per square yard	2.50	2.59	2.60

In the same city on March 21, 1919, three bids were presented for building pavements 6, 7 and 8 inches thick, as follows:

6-inch pavement, per square yard	$1.85	$2.00	$2.16
7-inch pavement, per square yard	2.15	2.26	2.40
8-inch pavement, per square yard	2.40	2.51	2.63

In the first piece of work referred to, the rate per inch of thickness per square yard under the low bid was approximately 31c per inch thickness for the 6-inch pavement, whereas the 7-inch pavement cost less than half that rate for the additional inch, to-wit: 13c. The same condition prevailed in the second job noted. In the bid for the City of Seattle, the 6-inch pavement cost approximately 31c per inch thickness per square yard, whereas the 7-inch thickness cost approximately the same rate, and the 8-inch thickness a cent less. The county bids on the basis of a pavement 16 feet in width show a difference in cost between the 6 and 7-inch pavements of approximately $1,220.00 per mile. The 6-inch pavement on the same job cost at the rate of $11.28 per cubic yard, whereas the 7-inch pavement cost $10.33 per cubic yard, or approximately 10 per cent less per cubic yard. In the City of Seattle the 7-inch pavement cost at the rate of $11.57 per cubic yard and the 8-inch pavement $11.25 per cubic yard, or a less difference in price per cubic yard than the difference in price between the 6 and 7-inch pavement, showing that the difference in rate bid per square yard is more apparent on the thinner sections than on those that are thicker. It follows that a much greater difference in cost per cubic yard will occur when the comparisons are made between pavements 4 inches thick and 6 or 8 inches thick.

TRAFFIC CENSUS OF STATE HIGHWAYS

A traffic census of the State highways coming within the scope of this report was made during the month of August, 1920. The passenger travel during this month is probably at its peak in that summer outings are being enjoyed. The number of trucks generally traveling throughout this section of the State is probably not as heavy during August as in September and October, or during the months of harvesting our principal crops. On the other hand, there was a great deal of hay and grain and miscellaneous loads, so that taking the month of August as a whole, the vehicular traffic will probably represent a normal condition.

Two men with suitable blanks were sent to designated points which were considered as representative of the sections under investigation. Generally a census was taken from 6 a. m. to 7 p. m., but in several cases a twenty-four hour count was made. Passenger automobiles were divided into two classes, light and heavy. The weight of a modern Cadillac 7-passenger touring car, 4,000 pounds, was taken as the dividing line between the two classes. The heavy class includes auto busses. It was estimated that the light class of automobiles carried an average of three passengers and baggage equivalent to one more passenger; and that the heavy cars carried an average of six passengers, with baggage equivalent to one more passenger. This estimate of passengers carried is borne out by the observation of 1,640 light cars and 466 heavy cars, supplementing the census.

Trucks were also counted and classified according to their rated capacity, varying from a one-ton truck, or the usual Ford type, to the heaviest truck operating at the present time of 7½-ton capacity. The loads and rated capacities of these were estimated by the observers. Some practice was taken by them and very often their estimates were checked with the actual

18-1 Loaded trucks on Ridge Road, Los Angeles County. One of the causes of wrecked pavements. There is gross disregard of law relative to both loads and speed of trucks.

Excessive irregular cracking and crushing down of pavement mile 3.0 north of Forest Reserve Inn, "Ridge Route," Los Angeles County.

weights. It was found that they were within 10 per cent of correct in all cases. A truck passing was counted and classified according to its rated capacity, and also according to the load it was carrying. If trucks were pulling trailers, this fact was recorded and also the weight of the load on the trailer.

The detailed results of this census will be found on pages 42 to 65, inclusive. Page 44 is a diagram and summary for a common twelve-hour period for the purposes of comparison of traffic. Page 45 is a tabulation of traffic count and tonnage expanded from traffic observed during the hours as indicated on the several station sheets to a twenty-four hour period. The expansion of the observed traffic was accomplished by the use of the traffic census as found by Los Angeles County. See page 50.

Thirteen different points on State highways were selected, one point on a county road and two points on city streets, to give a comparison of the traffic over these roads with the State highway. The sixteen points at which traffic was observed are as follows:

STATE HIGHWAYS

	Road From—	To—	Point of Observation
1	Los Angeles (Ridge Route)	Bakersfield	Saugus
2	Los Angeles (Mint Canyon Road)	Lancaster	Saugus
3	Los Angeles	Ventura	Universal City
4	Los Angeles	Ventura	Camarillo
5	Los Angeles (Foothill Boulevard)	San Bernardino	Lamanda Park
6	San Bernardino (Cajon Pass Road)	Victorville	Highland Junction
7	Santa Ana	San Diego	Tustin
8	Los Angeles	Whittier	End of Stephenson Ave.
9	Fresno	Bakersfield	Delano
10	Fresno	Bakersfield	Goshen Junction
11	Visalia	Hanford	Goshen Junction
12	Fresno	Bakersfield	Fowler
13	Santa Barbara	San Luis Obispo	Pismo

COUNTY ROAD

14	Los Angeles (South Main St.)	San Pedro	Nigger Slough

CITY OF FULLERTON

15	Commonwealth Ave.	At intersection
16	Spadra Road	At intersection

Page 46 is a diagram of summary traffic count in tonnages showing number of tons per hour per foot of traveled road and maximum loads. The zone of travel was obtained by observation of where it generally is in relation to the center line of the road. This table also shows maximum single gross loads on four wheels.

Page 47 shows diagrammatically number of loaded, empty, partially loaded, capacity loaded and overloaded trucks with the average and maximum overload in tons.

On page 48 is a summary showing numbers of overloaded trucks with the percentage of overload.

In this traffic count some two thousand trucks were observed and it is pleasing to note that the estimated weights were in fair agreement with those determined by actual weighing.

Class	No. Vehicles	Aver. Wt.	Max. Wt.	Total Tons	No. Vehicles	Aver. Wt.	Max. Wt.	Total Tons	No. Vehicles	Aver. Wt.	Max. Wt.	Total Tons	No. Vehicles	Aver. Wt.	Max. Wt.	Total Tons
	Ridge Route—Station Saugus Date: Aug. 6-7, Period 24 hrs.				**Mint Canyon**—Station Saugus Date: Aug. 6-7, Period 24 hrs.				**Ventura Rd.** at Universal City Aug. 9, 14 hrs.—5AM-7PM				**Ventura Rd.** at Camarillo Aug. 24, 12 hrs.—6AM-6PM			
Light Autos	631	2200	....	694.10	463	2200	....	509.30	818	2200	....	899.80	342	2200	....	376.20
Heavy Autos	88	5400	....	237.60	27	5400	....	72.90	160	5400	....	432.00	45	5400	....	121.50
1-ton truck	9	3833	5400	17.25	9	3733	5400	16.80	20	4450	7400	44.50	11	4127	5400	22.70
1½-ton truck	3	6000	7600	9.00	3	5200	....	7.80	8	5700	7200	22.80	7	6743	8200	23.60
2-ton truck	18	8872	13400	79.85	9	10733	16400	48.30	40	8868	14800	177.37	16	8525	12400	68.20
3-ton truck	14	9436	18400	84.92	9	13788	20400	62.05	54	12377	20400	334.20	9	11400	16400	51.30
5-ton truck	13	16923	24000	110.00	1	20000	....	10.00	6	12666	18000	38.00	1	10000	....	5.00
Totals	776			1232.72	521			727.15	1106			1948.67	431			668.50
	Cajon Pass—Highland Junc. Aug. 26-20, 12 hrs.—6AM-6PM				**L.A.-San Diego** at Tustin Aug. 13-20, 13 hrs.—6AM-7PM				**LA-Whittier Rd.**—Cemeteries Aug. 11-20, 14 hrs.—5AM-7PM				**Fresno-Bakersfield**—Delano Aug. 17-20, 13 hrs.—6AM-7PM			
Light Autos	203	2200	....	223.3	1202	2200	....	1322.20	2421	2200	....	2663.10	630	2200	....	693.00
Heavy Autos	11	5400	....	29.7	183	5400	....	494.10	281	5400	....	758.70	63	5400	....	170.10
1-ton truck	8	3400	....	13.6	24	4658	6400	55.90	80	4314	7400	172.55	20	4350	....	43.50
1½-ton truck	3	5200	....	7.8	1	8200	8200	4.10	24	6117	9200	73.40	6	5700	....	17.10
2-ton truck	2	7400	8400	7.4	23	9800	14400	112.71	64	8420	14400	269.48	27	9022	....	121.80
3-ton truck	2	12400	14400	12.4	22	10936	18400	120.30	93	11780	18400	547.82	12	13066	....	78.40
5-ton truck	....	....	....	....	1	16000	....	8.00	58	14758	22000	478.00	8	15250	....	61.00
Totals	229			294.2	1456			2117.31	3021			4963.05	766			1184.90
	Visalia-Hanford—Goshen Jct. Aug. 18-20, 13 hrs.—6AM-7PM				**Bakersfield-Fresno**—Fowler Aug. 19-20, 13 hrs.—6AM-7PM				**S.L. Obispo-S. Barbara**—Pismo Aug. 23-20, 12 hrs.—6AM-6PM				**Commonwealth Av**—Fullerton Aug. 27-20, 12 hrs.—6AM-6PM			
Light Autos	550	2200	....	605.00	2146	2200	....	2360.6	638	2200	....	701.80	2066	2200	....	2272.60
Heavy Autos	36	5400	....	97.20	226	5400	....	610.2	72	5400	....	194.40	90	5400	....	243.00
1-ton truck	33	3872	7400	63.90	51	4206	7400	107.25	5	3400	3400	8.50	40	4025	7400	80.50
1½-ton truck	3	7200	8200	10.80	14	6057	11200	42.40	3	5866	7200	8.80	29	5924	9200	85.90
2-ton truck	21	8590	10400	90.20	71	7958	12400	282.50	2	7400	8400	7.40	75	9184	12400	344.40
3-ton truck	16	11275	16400	90.20	39	12600	17400	246.70	16	11662	17400	93.30	27	10700	16000	149.40
5-ton truck	7	19428	24000	68.00	5	16800	24000	42.00	8	18000	24000	72.00	15	17520	24000	131.40
Totals	666			1025.30	2552			3691.65	744			1086.20	2342			3307.20
	L.A.-San Pedro—Nigger Slough Aug. 30-20, 16 hrs.—5AM-9PM				**Foothill Blvd.**—Lamanda Pk. Aug. 10, 14 hrs.—5AM-7PM				**Fresno-Bakersfield**—Goshen Jt Aug. 18-20, 13 hrs.—6AM-7PM				**Spadra Road**—City Fullerton Aug. 27-20, 10 hrs.—8AM-6PM			
Light Autos	1981	2200	....	2179.10	1204	2200	....	1324.40	651	2200	....	716.10	3964	2200	....	4360.4
Heavy Autos	214	5400	....	577.80	145	5400	....	391.50	49	5400	....	132.30	342	5400	....	923.40
1-ton truck	61	4556	7400	138.95	37	4319	5400	79.90	24	4108	7400	49.30	61	3826	5400	116.70
1½-ton truck	34	6852	9200	116.48	8	6325	8200	25.30	2	8200	8200	8.20	49	5629	9200	137.90
2-ton truck	91	8479	13400	385.80	31	8432	12400	130.70	26	8936	12400	116.17	124	8263	12400	512.30
3-ton truck	68	12700	18400	431.51	11	11036	14400	60.70	10	10000	14400	50.00	52	10573	16400	274.91
5-ton truck	127	17490	26000	1110.42	7	14285	....	50.00	7	21143	24000	74.00	20	16950	24000	169.50
7½-ton truck	2	26800	27800	26.80	....	....	....	....	....	....	....	....	....	....	....	....
Totals	2578			4966.86	1443			2062.50	763			1146.07	4612			6495.11

Table No. 6

SUMMARY TRAFFIC COUNT & TONNAGES

ON CERTAIN STATE & COUNTY HIGHWAYS 6AM TO 6PM
DURING AUG. 1920 (ONE WEEK DAY AT EACH STATION)

TONNAGE FROM ESTIMATES

LIGHT AUTOS	HEAVY AUTOS	TRUCKS	TOTALS
482	208	200	890
385	49	123	557
830	392	519	1741
376	121	214	711
1164	367	436	1967
223	32	73	328
1139	459	300	1898
2419	702	1375	4496
637	154	373	1164
642	124	337	1103
550	86	355	991
2035	575	845	3455
702	194	150	1046
1830	481	1730	4041
2273	264	845	3391
4530	978	1550	7058

UNSHADED LIGHT AUTOS
SHADED HEAVY AUTOS & TRUCKS

Count at Camarillo is not normal account Conejo Grade being closed for reconstruction.

AVERAGE GROSS WEIGHTS

Light Autos	1.1 TONS
Heavy Autos	2.7 TONS
Trucks	4.55 TONS

NOTE — Automobile classification changes at weight of 4000 lbs.; or Cadillac and heavier classed as heavy; others as light.

Engineering Offices
J. B. Lippincott
Sept. 1920

Table No. 7

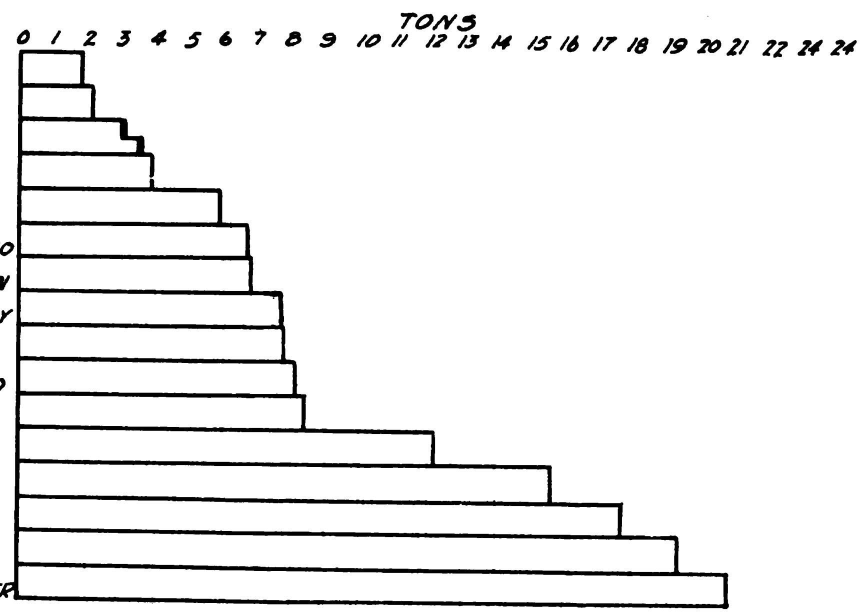
SUMMARY OF TRAFFIC COUNT AND TONNAGES ON STATE HIGHWAY POINTS
EXPANDED TO 24 HOURS
EXPANSION FROM OBSERVED HOURS TO 24 HOURS
BASED ON LOS ANGELES COUNTY ROAD DEPARTMENT'S COUNT

ROAD	Day 6 A. M. to 6 P. M.		Night 6 P. M. to 6 A. M.							
	Autos	Trucks	Autos	Trucks (Estimates based on traffic count taken by L. A. County)	Total Autos	Total Trucks	Total Vehicles	Tonnage Autos	Tonnage Trucks	Total Tonnage
Ridge Route	515	44	204	13	719	57	776	898	260	1158
Mint Canyon	368	27	122	4	490	31	521	612	141	753
L. A. to Ventura—Univ. City	900	113	342	24	942	137	1079	1177	624	1801
L. A. to Ventura—Camarillo	387	47	147	10	534	57	591	668	260	928
Foothill Blvd.	1094	96	416	20	1510	116	1626	1887	527	2414
Cajon Pass	215	16	82	3	297	19	316	371	36	457
Santa Ana to San Diego	1205	66	458	14	1663	80	1743	2080	364	2444
Los Angeles to Whittier	2459	303	935	64	3394	367	3761	4242	1670	5912
Fresno to Bakersfield—Delano	636	82	242	17	878	99	977	1097	450	1547
Fresno to Bakersfield—Goshen	630	76	240	16	870	92	962	1088	419	1507
Visalia to Hanford	532	78	202	16	734	94	828	919	428	1347
Fresno to Bakersfield—Fowler	2063	185	792	39	2855	224	3079	3569	1020	4589
Santa Barbara to San Luis Obispo	710	33	270	7	980	40	1020	1125	182	1307
Los Angeles to San Pedro	1841	380	700	80	2541	460	3001	3176	2095	5271
Com'th Ave.	2164	186	824	39	2988	225	3213	3735	1023	4758
Spadra Road	4480	341	1700	71	6180	412	6592	7725	1877	9602

Table No. 8

SUMMARY TRAFFIC COUNT & TONNAGES

TABLE - SHOWING NUMBER OF TONS PER HOUR PER FOOT OF TRAVELED ROAD AND MAXIMUM LOADS



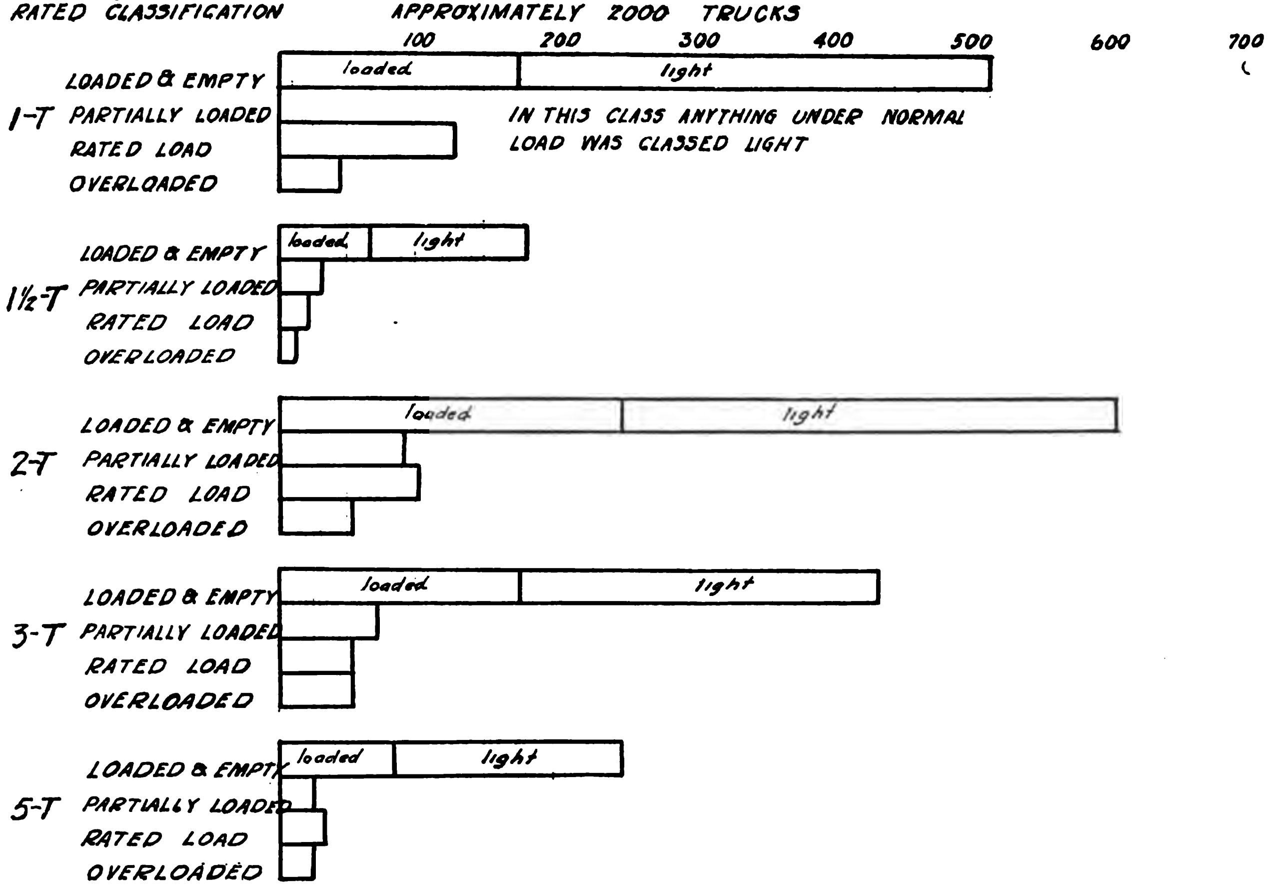
ROAD	ACTUAL WIDTH OF ROAD IN FEET	WIDTH OF TRAVELED PATH IN FEET	AMOUNT OF TRAFFIC IN PATH IN PERCENT	MAXIMUM SINGLE GROSS LOAD ON 4 WHEELS IN TONS - OBSERVED
MINT CANYON	20	14	90	10.2
CAJON PASS	15	10	90	7.2
RIDGE ROUTE	20 15	14 12	90 90	12.8
L.A. TO VENTURA - CAMARILLO	15	12	90	8.2
VISALIA TO HANFORD	15	12	90	12.0
FRESNO - BAKERSFIELD - DELANO	15	12	90	11.0
FRESNO - BAKERSFIELD - GOSHEN	15	12	90	12.0
L.A. TO VENTURA - UNIVERSAL CITY	20	16	90	9.0
COMMONWEALTH AVE - FULLERTON	72	30	85	12.0
SANTA BARBARA - SAN LUIS OBISPO	15	10	90	12.0
FOOTHILL BOULEVARD	18	16	90	11.0
SANTA ANA - SAN DIEGO	15	12	90	8.0
L.A. TO SAN PEDRO	20	16	85	13 9
L.A. TO WHITTIER	20	18	90	10.4
SPADRA ROAD - FULLERTON	60	30	90	12.0
FRESNO - BAKERSFIELD SO. OF FOWLER	15	12	90	12.0

Engineering Offices
J. B. Lippincott
Aug. 1920

Table No. 9

SUMMARY TRAFFIC COUNT

TABLE - SHOWING NUMBER OF TRUCKS EMPTY, LOADED, PARTIALLY LOADED LOADED TO RATING AND OVERLOADED BASED ON ROAD ESTIMATE OF APPROXIMATELY 2000 TRUCKS



Rated classification	AVERAGE OVERLOAD IN TONS	MAXIMUM OVERLOAD ON ANY TRUCK IN TONS
1-T	0.68	1.00
1½-T	0.69	1.80
2-T	1.01	3.00
3-T	1.50	3.00
5-T	1.65	3.00

SHADED PORTION - LOADED TRUCKS
UNSHADED PORTION - EMPTY TRUCKS

Engineering Offices
J. B. Lippincott
Aug. 1920

Table No. 10

SUMMARY TRAFFIC COUNT

Tables showing numbers of overloaded trucks from approximately 2,000 observed, with the per cent of overload based on their rated capacity.

Numbers and per cent of total number of overloaded trucks

Per Cent Truck is Overloaded	1 Ton		1½ Ton		2 Ton		3 Ton		5 Ton	
	No.	%	No.	%	No.	%	No.	%	No.	%
25%	....	....	2	15	19	28	31	48	35	46
50%	21	64	6	46	39	56	26	39	36	48
75%	....	....	4	31	5	7	6	9	5	6
100%	12	36	1	8	6	9	3	4	0	0
Totals	33	100	13	100	69	100	66	100	75	100

This is the first general traffic study which is available for the State highways of Southern California. Table No. 6, page 44, is a summary in which an estimate has been prepared adjusting the number of vehicles and the tonnage to a common twelve-hour basis for all observed points for purposes of comparison. It shows a wide variation in the use of these roads; Cajon Pass having 250 vehicles per twelve hours and the Los Angeles-Whittier Boulevard, at the cemeteries, having 2,800 vehicles. The Spadra Road in Fullerton, on the line of the State Highway, cannot be used in this comparison because the point of observation was in the town. There should be some relation between the volume of traffic passing over a road and the width of the road, the topography being the same. The State Highway Commission generally adopted the policy of widening the road as it approaches the larger cities and to a certain extent widening the trunk roads where the travel is heaviest, but generally speaking the standard width of 15 feet has been applied on all State highways. This widening of the road to meet traffic conditions is being met by the State Highway Commission frequently by the addition of shoulders rather than in the original design.

The last column in Table No. 6 shows the tonnage passing over these respective roads. This has even greater variation, 328 tons per twelve hours having been observed on the Cajon Pass, 4,496 tons on the Whittier-Los Angeles road and 7,058 tons on the Spadra road in Fullerton, all between 6 a. m. and 6 p. m. From an engineering and practical standpoint there should be some rational relation between the tonnage on a road and the thickness of its pavement. The inspection of the present condition of Southern California roads does not show such direct relation because the life of the pavement is largely determined by the character of the foundation. If all conditions could be taken under consideration there must be some relation between the life of the road and the service to which it is put. The County of Los Angeles is taking this into consideration in the construction of its Harbor Truck Boulevard, which is to be a reinforced 8-inch slab laid on 6 inches of decomposed granite. It is proposed to build 1,798 miles of new roads under the Third Bond Issue. A large amount of the pavements on the main trunk lines of the State highways also will have to be resurfaced before many years. The roads that are designed and built in the future should take into consideration not only the condition of their foundations but the volume of traffic in determining their width and the weight of the traffic in fixing the thickness of the slab. While these dimensions must be more or less empirically determined, some such traffic study as is here presented is essential to a satisfactory formation of judgment.

An effort has been made in the report of the Committee on Maintenance to compare upkeep cost per mile and per square yard of pavement with the tonnage passing over the road. The same difficulties arise in such a study as indicated above because of variation in foundation conditions, the quality of workmanship, class and speeds at which the traffic moves. If all the facts entering into this subject were available, there should be some relation existing between the tonnage passing over the road and its annual maintenance cost per mile. The cost of a road to a community in its final and accurate analysis must be expressed in the charge per ton mile of the traffic passing over it.

Crushed edge of pavement 6 miles north of Grapevine Station, Kern County. Note the necessity of shoulders on this class of soil. This is very dangerous to traffic on narrow pavements.

Triangular breaks and displacement of pavement, mile 7.0, north of Grapevine Station, Kern County.

Table No. 9, page 47, shows the estimated weight and overloading of approximately 2,000 trucks on the state highways at points widely distributed throughout Southern California. This is a matter of estimating and not weighing of these loads, but the observers were checked up on approximately 500 trucks which were actually weighed and it was found that their judgment was accurate within about ten per cent, as previously noted. This table shows that twelve 1-ton trucks were overloaded 100% as compared with the manufacturer's rating. One 1½-ton truck, six 2-ton trucks and three 3-ton trucks were also found overloaded 100%. These estimated weights show that the trucks traveling at remote and scattered points throughout the country are following much the same practice of overloading that was found to be the case with the trucks weighed in the City of Los Angeles on standard scales. The owners of the trucks seem to be perfectly willing to overload their vehicles when they have good pavements to travel on, disregarding both the recommendations of the manufacturers and the state laws.

Los Angeles County Road Department's Traffic Count on County Roads

The Los Angeles County Road Department has kept a count of traffic passing over the principal paved roads of the County since 1914. It was made in four six-hour shifts divided over the twenty-four hours of each day, and each six-hour shift was taken for seven continuous days. The results thus obtained were totaled to show the average of seven continuous days of traffic over the road. The counts were taken in hour periods, in order to determine the fluctuations of traffic during the day.

The results of the Road Department's count is indicated below, showing travel of automobiles and motor trucks over the following roads:

Slauson Ave. at Santa Fe Ave.
Washington Blvd. at City Limits.
Compton Ave. at Slauson Ave.
Valley Blvd. or Telegraph Road at Downey.
Monterey Pass at Metallic Brick Company's Yd.
El Monte Road at El Monte Bridge.
Long Beach Blvd. at City Limits.
Harbor Blvd. at City Limits.

As noted on page 42, the results of County Census were used to complete the State Highway census.

A table has been made from this data showing the relation between the travel during the night hours and that during the day hours, which follows:

Table No. 11
Los Angeles County Road Department
1920 Traffic Counts

Station	Automobiles			Motor Trucks		
	Day 6 A. M. to 6 P. M.	Night 6 P. M. to 6 A. M.	Night % Day	Day 6 A. M. to 6 P. M.	Night 6 P. M. to 6 A. M.	Night% Day
Slauson Ave.	3619	1041	29%	539	90	17%
Washington Blvd.	3457	3487	......	161	32	20%
Compton Ave.	2339	887	38%	244	51	21%
Valley Blvd.	878	479	55%	118	16	14%
Monterey Pass	1408	420	30%	162	17	11%
El Monte Road	2230	820	37%	401	143	36%
Long Beach Blvd.	4819	2251	47%	313	62	20%
Harbor Blvd.	3249	907	28%	413	109	27%
		Average	38%		Average	21%

The night automobile traffic is 38% of the day traffic and the night truck traffic is 21% of the day traffic between the hours indicated. These average figures applied to the twelve hour counts taken on the state highways in Table No. 7, page 45, gives the total tonnage carried by these state highway routes for twenty-four hours.

AUTOMOBILE AND TRUCK CENSUS CITY OF LOS ANGELES

As a matter of general interest, bearing on automobile traffic over various highways, the following results of a study of vehicles entering and leaving the City of Los Angeles are attached. An actual count of all autos and trucks entering and leaving the city was made, covering the daylight period from 8 a. m. to 6 p. m., June 28, 29 and 30, 1920. Observations were taken at fifteen selected stations on the main arteries of traffic.

In the table below and on the chart (next page) these stations are grouped together in four groups, as indicated. The figures show the hourly flow of traffic averaged for the three days. This count was made for the Automobile Club of Southern California.

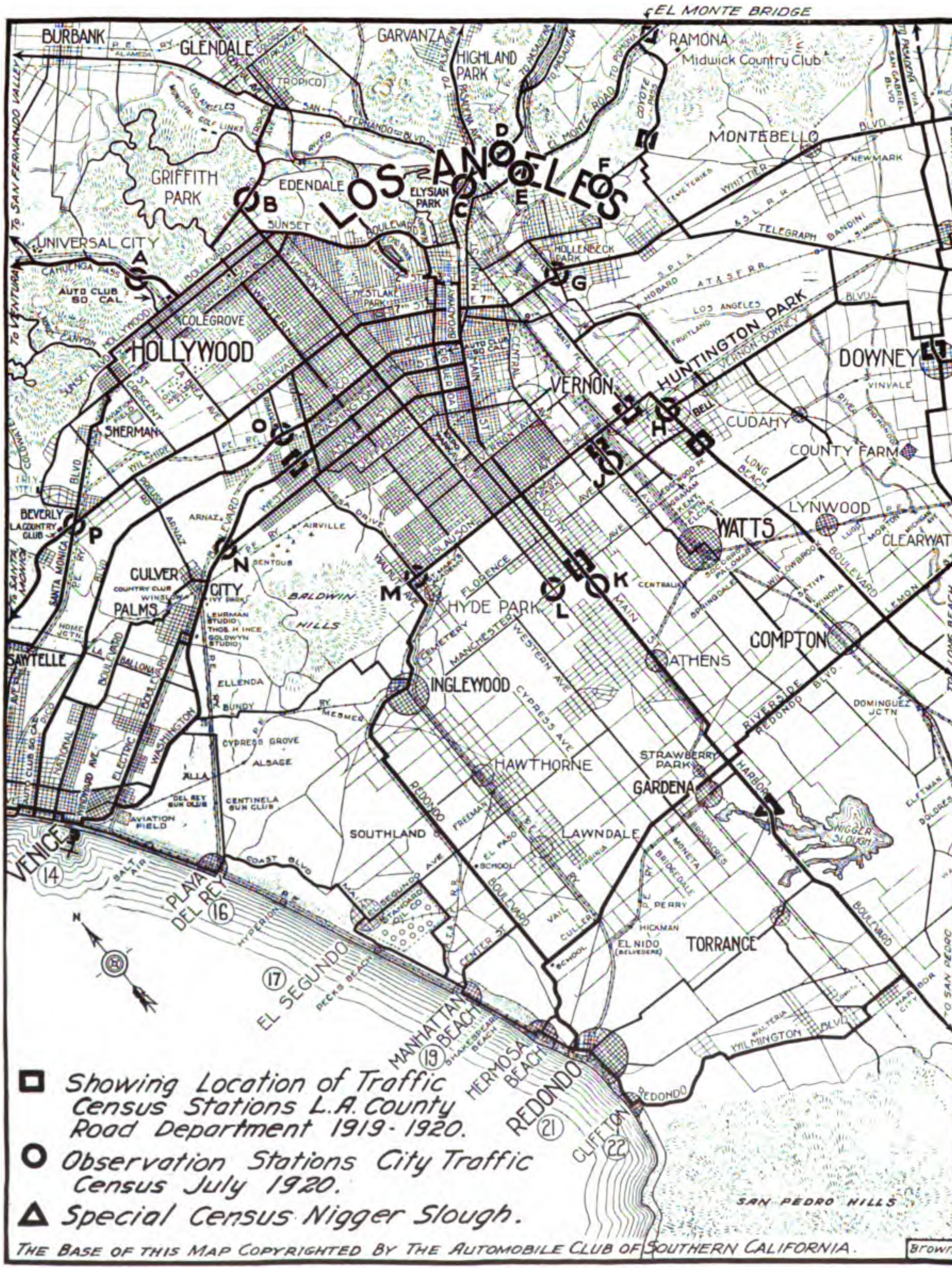
AVERAGE TRAFFIC COUNT
For June 28-29-30, 1920
TABLE NO. 12

Station	San Fernando Valley Points A,B and Part of C		Pasadena and San Gabriel Valley Points Bal. of C, D, E, F		Whittier and Santa Ana Valley Points G		Beach Points H, J, K, L M, N, O, P		TOTALS	
									Inbound	Out-bound
Time	In	Out	In	Out	In	Out	In	Out		
8.00- 8.30....	300	256	325	214	112	78	452	330	1189	878
8.30- 9.00....	297	219	340	209	108	116	403	358	1148	902
9.00- 9.30....	276	263	283	214	117	136	407	402	1083	1015
9.30-10.00....	271	255	294	256	105	98	341	389	1011	998
10.00-10.30....	260	229	225	224	135	133	365	416	985	1002
10.30-11.00....	269	255	258	225	121	110	382	435	1030	1025
11.00-11.30....	259	243	233	230	94	92	364	402	950	967
11.30-12.N....	261	270	234	240	85	105	330	373	910	988
12.00-12.30....	198	188	207	203	84	105	307	395	796	891
12.30- 1.00....	212	182	232	209	92	99	320	385	856	875
1.00- 13.0....	214	195	174	197	102	72	328	356	818	820
1.30- 2.00....	293	282	265	284	112	104	326	419	996	1089
2.00- 2.30....	267	257	211	231	107	104	401	442	986	1034
2.30- 3.00....	274	241	269	296	111	94	399	478	1053	1109
3.00- 3.30....	318	352	249	287	92	109	391	443	1050	1191
3.30- 4.00....	331	290	271	278	116	113	461	451	1179	1132
4.00- 4.30....	317	318	249	309	133	135	617	540	1316	1302
4.30- 5.00....	406	396	326	346	146	152	664	529	1542	1423
5.00- 5.30....	413	418	259	359	125	217	726	598	1523	1592
5.30- 6.00....	353	373	247	384	104	149	539	586	1243	1492
	5789	5482	5151	5195	2201	2321	8523	8727	21664	21725

On the accompanying Map No. 2, page 52, are indicated the points of observation.

The purpose of the traffic count on the main highways entering Los Angeles, as shown in Table No. 12, page 51, which was made on week days, was to determine how many of the vehicles approaching the city passed through it to points beyond and how many had the city itself as their destination. The registration number of each car was taken and the direction of its movement. A detailed study was then made to determine how many of these cars approaching the city passed out of it to points beyond. The prime purpose was to find whether the congestion of the traffic in the city could be relieved substantially by construction of good roads around its perimeter in such a way as to not only relieve congestion in the city itself but to facilitate and expedite the suburban traffic. The results show that but three per cent of the machines entering the city pass beyond it immediately. Therefore, 97% of all these machines were coming into the city to transact business. The deduction is plain that the relief of the downtown congestion must come from the improvement of the street system in and around the business district.

This investigation was conducted by the Automobile Club of Southern California. It has been made the subject of a detailed report to that organization with recommendations for the development of a belt line system of streets around the congested district.


EL MONTE BRIDGE
BURBANK
GLENDALE
GARVANZA
HIGHLAND PARK
RAMONA
Midwick Country Club
MONTEBELLO
GRIFFITH PARK
EDENDALE
ELYSIAN PARK
LOS ANGELES
UNIVERSAL CITY
AUTO CLUB SO. CAL.
COLEGROVE
HOLLYWOOD
HOLLENBECK PARK
HUNTINGTON PARK
VERNON
DOWNEY
CUDAHY
COUNTY FARM
SHERMAN
BEVERLY
LA COUNTRY CLUB
LYNWOOD
WATTS
CLEARWATER
CULVER CITY
PALMS
BALDWIN HILLS
HYDE PARK
SAWTELLE
INGLEWOOD
COMPTON
ATHENS
HAWTHORNE
STRAWBERRY PARK
GARDENA
NIGGER SLOUGH
SOUTHLAND
LAWNDALE
VENICE
PLAYA DEL REY
EL SEGUNDO
MANHATTAN BEACH
HERMOSA BEACH
REDONDO
CLIFTON
TORRANCE
SAN PEDRO HILLS
TO LONG BEACH
TO SAN PEDRO
Showing Location of Traffic Census Stations L.A. County Road Department 1919-1920.
Observation Stations City Traffic Census July 1920.
Special Census Nigger Slough.
THE BASE OF THIS MAP COPYRIGHTED BY THE AUTOMOBILE CLUB OF SOUTHERN CALIFORNIA.
Brown

WEIGHING OF TRUCKS ON PUBLIC SCALES IN CITY OF LOS ANGELES

From August 18, to August 20, and again from September 3 to September 8, men were stationed at the Licensed Public Scales of the Los Angeles Ice & Cold Storage Company at Fourth and Central Streets, and of the Los Angeles Hay Market on North Los Angeles Street, near the Plaza. These men were instructed to get the following data regarding all trucks weighed:

(1) Make of truck.
(2) Manufacturer's rated capacity.
(3) Weight of truck loaded and empty and net load carried.
(4) Width of tire exposed to pavement, if solid, and the per cent of pneumatic tires used.
(5) Condition of tires (good or poor).
(6) Class of load carried.

In addition to this data, several weigh-masters in the county were asked to co-operate by sending in weights for various sizes of trucks weighed on their scales.

The object in mind was to get data regarding the average and maximum loads carried by trucks by actual measurements, and also as a comparison with estimated loadings being made on the highways in all parts of this region. Tables by the Engineers taking traffic census give the information collected.

During this time, data was taken on 472 trucks and 117 trailers. 454 of the trucks and all of the trailers had solid rubber tires on the rear wheels.

Table No. 13, page 55, shows the maximum and average loads carried by the various sizes of trucks. It is very important to notice that the **average loads** carried exceed in every case the rated capacity, and as for maximum a 3½-ton truck carried 19,570 pounds gross (9.7 tons), which was 6.28 tons or 2.79 times the load it was designed to carry.

The above table also shows the maximum and average load concentration of one rear wheel on approximately 500 trucks. This diagram should be of value in future design of roadways.

Tables Nos. 13 and 14, pages 55-56, show, in addition to the average and maximum loads carried, the percentages loaded under capacity, capacity, capacity to 1-ton overload, 1 to 2 tons overload, 2 to 3 tons overload, 3 to 4 tons overload, and greater than 4 tons overload, the average and maximum rear wheel loads, the percentage of trucks measured using county or state roads, and percentage of various loads carried.

Violation of State Law Regarding Loads per Inch of Tire Width as Fixed by the Motor Vehicle Act

Table No. 15, page 56, gives data concerning the load on the pavement per inch width of tire. Violations of the State Law regarding allowable load per inch width of tire were found to be very numerous, ranging from 46% for ½-ton trucks up to 84% for 4-ton trucks. The weight of a truck and its load is unevenly distributed to the front and rear wheels, and thereby to the pavement. In this study 75% of the gross load is considered as being applied to the pavement by the two rear wheels. This percentage is used by tire manufacturers in computing size of tires for various capacities of trucks. This proportion is also checked by use of loadometers which are devices for measuring weights of trucks at any place.

The State Law says, "No motor or other vehicle . . . . shall be operated or moved upon or over any public highway or bridge, the weight of which resting upon the surface of said highway or bridge exceeds 800 lbs. upon any inch width of tire . . . ." The widths of tire measured in the observations were taken at the top of the tire, and not at the base, so that these widths are not those given by the manufacturer. They were also taken at a point on the tire not under compression at the time. From tests made by a large tire manufacturer on the spread of a

new 10″ solid tire under capacity loading, it is shown that the increase in width is about 15%. Since the tires measured were, in most cases, more or less worn down, and since the resiliency of a tire decreases with the increase in the percentage worn, the percentage of spreading would be considerably less than 15%, and is therefore neglected.

Table No. 15, page 56, gives data on the condition and use of tires found on the trucks weighed.

From the above tables it can be seen that even the average loads per inch width of rear tire exceed in every case that allowed by the law, and maximum loads in several cases exceed double that allowed by the law. Of the trucks overloaded above 800 lbs. per inch of tread, it is found that the average **overload** ranges from 109 lbs. per inch width tire for a 3-ton truck to 345 lbs. per inch width of tire for a 3½-ton truck, while the maximum **overload** per inch of tire width was 1,040 lbs. on a 5-ton truck. In addition to this flagrant violation of the State Law, it was found that quite a few of the trucks carried poor tires, reaching a maximum of 41½% in the case of the 5-ton trucks.

These violations cannot properly be laid at the door of the truck manufacturer who has outfitted the car with a size of tire which, according to standards adopted by the Society of Automotive Engineers, is adequate for its rated capacity. Any departure from this rating in the direction of overload can be blamed on the owner and operator, and in some cases to the truck dealer. For example, the advertisement of the work of a 2-ton truck with an 8-ton load on it. This latter fact is responsible for a great deal of the deliberate overloading by the operator. The overloading reflects directly upon the condition of the tires, breaking down and crystallizing the rubber, and thus adds to the destruction of the surface of the road. Excessive speeding will also break down the tire by overheating it, and in some cases causing it to blow up.

Diagram No. 4, page 57, shows total truck tonnage and average weights per truck, the upper half being 1,256 trucks weighed, and the lower half for 2,004 truck loads estimated by census takers.

Diagram No. 5, page 58, graphically illustrates the average weight of empty and loaded trucks.

Table No. 13

SHOWING DATA COLLECTED REGARDING LOADS CARRIED BY APPROXIMATELY 500 TRUCKS WEIGHED ON PUBLIC SCALES IN THE CITY OF LOS ANGELES AND APPROXIMATELY 130 TRUCKS WEIGHED IN DIFFERENT PARTS OF LOS ANGELES COUNTY

		Rated Capacity in Tons							
		1	1½	2	2½	3	3½	4	5
1.	Gross Weight: Total pounds	731865	563815	1178485	1752581	439018	947565	1005335	2315980
2.	Gross Weight: Number trucks weighed	114	61	93	128	27	51	53	110
3.	Gross Weight: Average pounds	6420	9243	12672	13692	16259	18580	18968	21054
4.	Gross Weight: Maximum pounds	11400	13750	21500	25175	23800	29280	26860	30085
5.	Empty Weight: Total pounds	332185	269925	589846	820565	202860	466225	448240	1024710
6.	Empty Weight: Number trucks weighed	112	58	94	127	27	53	53	95
7.	Empty Weight: Average pounds	2965	4654	6275	6461	7520	8797	8457	10786
8.	Net Load Carried: Total pounds	388520	264975	590669	899276	236158	498425	558790	1083215
9.	Net Load Carried: Number trucks weighed	111	58	92	124	27	51	52	100
10.	Net Load Carried: Average pounds	3500	4568	6420	7252	8747	9773	10746	10832
11.	Net Load Carried: Maximum pounds	6830	9040	12180	16825	15575	19570	16920	18800
12.	Per cent of trucks weighed using State or County Highways	59%	54%	59%	58%	60%	69%	84%	43%
13.	Average concentration of load—1 rear wheel	2410	3468	4755	5130	6232	6965	7115	7895
14.	Maximum concentration of load—1 rear wheel	4275	5159	8062	9438	8925	10960	10075	11280
	CHARACTER OF LOADS CARRIED IN PER CENT OF TOTAL TRUCKS WEIGHED								
15.	Hay	11.5	6.7	16.9	13.3	28.6	24.4	64.2	32.3
16.	Grain	3.9	......	12.7	2.2	......	9.8	5.2	5.4
17.	Farm Produce	31.2	33.3	22.5	32.2	28.5	12.2	20.3	9.7
18.	Machinery	1.3	......	1.4	3.3	......	12.2	......	1.0
19.	Scrap Metal	39.0	6.7	11.3	14.5	......	9.7	......	17.2
20.	Rolled Steel	1.3	10.0	2.8	7.8	......	4.9	7.7	23.6
21.	Furniture	2.6	20.0	15.5	11.1	28.6	17.1	2.6	5.4
22.	Paper	2.6	10.0	7.0	7.8	......	......	......	2.2
23.	Miscellaneous	6.6	13.3	9.9	7.8	14.3	9.7	......	3.2

Table No. 14

DATA COLLECTED REGARDING OVERLOADS CARRIED BY TRUCKS WEIGHED ON PUBLIC SCALES IN LOS ANGELES

	Capacity of Trucks							
	1	1½	2	2½	3	3½	4	5
1. No. of trucks under capacity	14	14	13	18	8	6	5	46
2. Percentage of trucks under capacity	13.6	23.34	18.08	14.29	28.58	9.68	7.14	36.80
3. No. of trucks at capacity	9	3	3	8	2	3	1	8
4. Percentage of trucks at capacity	8.42	5.00	4.16	6.37	7.15	4.84	1.43	6.40
5. No. of trucks capacity to one ton overload	37	19	16	27	3	15	12	34
6. Percentage of trucks capacity to one ton overload	34.60	31.66	22.22	20.75	10.72	24.19	17.15	27.20
7. No. of trucks one to two tons overload	44	17	18	48	4	20	36	17
8. Percentage of trucks one to two tons overload	41.11	28.35	25.00	38.13	14.28	32.25	51.42	13.60
9. No. of trucks two to three tons overload	3	6	17	18	3	11	12	13
10. Percentage of trucks two to three tons overload	2.81	10.00	23.60	14.29	10.71	17.75	17.15	10.40
11. No. of trucks three to four tons over-overload	.....	1	1	3	4	3	3	4
12. Percentage of trucks three to four tons overload	.....	1.65	1.39	2.39	14.28	4.84	4.28	3.20
13. No. of trucks over four tons overloaded	.....	.....	4	4	4	4	1	3
14. Percentage of trucks over four tons overloaded	.....	.....	5.55	3.78	14.28	6.45	1.43	2.40

Table No. 15

DATA COLLECTED REGARDING TIRE LOADS ON APPROXIMATELY 500 TRUCKS WEIGHED IN THE CITY OF LOS ANGELES. TIRE WIDTHS BASED ON WEARING SURFACE OF TIRE. LOADS FIGURED AS 75% ON REAR WHEELS

	Rated Capacity in Tons							
	1	1½	2	2½	3	3½	4	5
1. Average width of 1 solid rear tire (ins.)	2.23	4.08	5.48	5.76	7.70	7.38	9.35	9.67
2. Percentage of trucks having pneumatic rear tires	2.72%	8.56%	.....	3.90%	20%	.....	.....	.....
3. Average speeds (miles per hour)	18.4	19.6	17.6	16.5	14.75	15.5	15.5	15
4. Per cent of trucks having poor tires*	10.8%	16.7%	20.2%	27%	.....	10.2%	25.7%	41.5%
5. Average load per 1" width of rear tires (lbs.)	912	831	895	832	888	958	978	1090
6. Maximum load per 1" width of rear tire (lbs.)	1538	1317	1612	1520	957	1568	1677	1840
7. Per cent of trucks overloaded based on 800 lbs. per 1" width of rear tire	74.6%	46.8%	69.2%	53%	75%	70.5%	84%	66.6%
8. Average overload per 1" width of rear tire (lbs.)	259	235	257	223	109	345	313	292
9. Maximum overload per 1" width of rear tire (lbs.)	738	517	812	720	157	768	877	1040
10. Overload on front tires	.....	.....	.....	.....	.....	.....	.....	.....

*Good tire—presenting a smooth surface of even width to pavement.

*Poor tire—notched, uneven, rough surface or worn down to steel base.

Diagram No. 4

TOTAL TRUCK TONNAGE & AVERAGE WEIGHTS PER TRUCK

ACTUAL WEIGHTS ON PUBLIC SCALES
1256 WEIGHINGS

NUMBER WEIGHED		AVERAGE WEIGHT TONS		
EMPTY	LOADED	GROSS LOAD	EMPTY	NET PAY LOAD
112	114	3.21	1.48	1.73
58	61	4.62	2.32	2.30
94	93	6.33	3.14	3.19
127	128	6.85	3.23	3.62
27	27	8.13	3.76	4.37
53	51	9.29	4.39	4.90
53	53	9.48	4.23	5.25
95	110	10.52	5.39	5.13

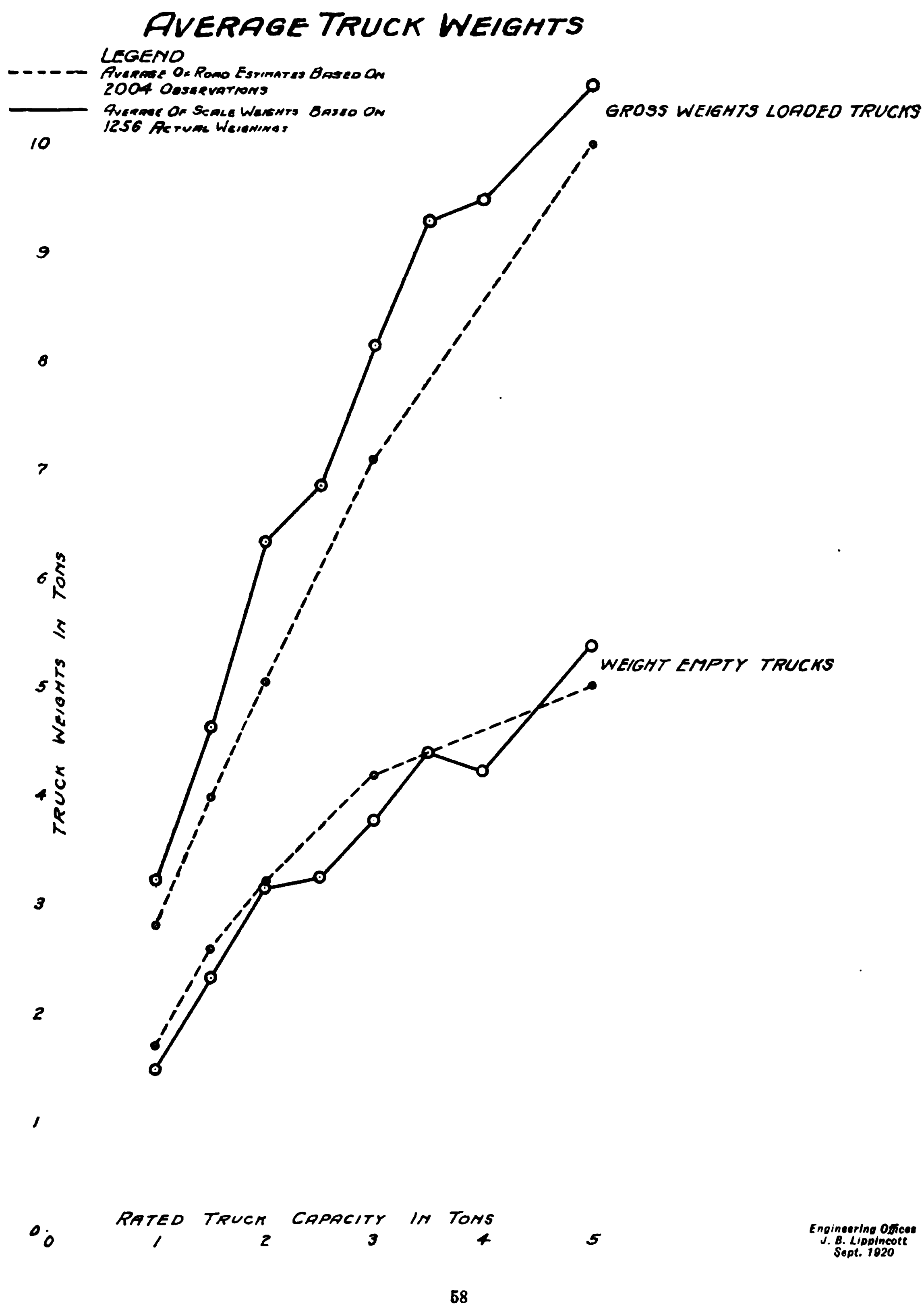
ROAD OBSERVATION ESTIMATES
2004 OBSERVATIONS

NUMBER OBSERVED		AVERAGE WEIGHT TONS		
EMPTY	LOADED	GROSS LOAD	EMPTY	
346	174	2.81	1.70	
115	68	3.98	2.60	
250	362	5.05	3.20	
176	253	7.10	4.20	
84	166	10.00	5.00	

UNSHADED EMPTY TRUCK TONNAGE
SHADED PAY LOAD TONNAGE

Engineering Offices
J. B. Lippincott
Sept. 1920

Diagram No. 5


AVERAGE TRUCK WEIGHTS
LEGEND
Average of Road Estimates Based on 2004 Observations
Average of Scale Weights Based on 1256 Actual Weighings
GROSS WEIGHTS LOADED TRUCKS
WEIGHT EMPTY TRUCKS
TRUCK WEIGHTS IN TONS
RATED TRUCK CAPACITY IN TONS
0
1
2
3
4
5
6
7
8
9
10
Engineering Offices
J. B. Lippincott
Sept. 1920

Truck Weights by Loadometer

To have full data regarding overloads on highways, some method must be adopted of weighing trucks anywhere on the highways. Two weighing jacks known as "Loadometers," manufactured by Black & Decker, Baltimore, Maryland, were procured. One of the principal items of interest in the investigation is the proportion of load thrown on the rear axle by different loadings. It was found that the average rear axle loading is 75.3% of the gross load. This figure applies to all capacities of trucks. In the five-ton class, the minimum and maximum percentage of weight on the rear axle was found to be 69% and 87%, respectively, of the total gross load, the lighter relative loading on the rear wheel being pig iron and hay the heavier. One 6-ton truck was weighed which had a total load of 44,292 pounds, 80% of which was on the rear wheels or a weight per real wheel of 17,916 pounds. 10,000 lbs. maximum load on any wheel was used by the Committee on Slab Design in computing stresses in slab as shown by their accompanying report.

Description of Loadometer

The Loadometer used is in the form of a screw jack, the nut portion of the jack being set in an 8-inch cylinder filled with oil, this cylinder forming the base of the jack. As the jack is screwed out and takes the load, the pressure is transmitted through the oil into an ordinary hydraulic pressure gauge. This gauge is graduated to 20,000 pounds. The jack stems have a travel of four inches and with two different sized heads give them a wide enough range so as to be put under and lift any truck found. The jacks weigh 45 pounds each.

Description of Their Use

The Loadometers were taken to the scales at the Los Angeles Ice & Cold Storage Plant at 4th Street and Central Avenue, Los Angeles, and tested for accuracy. Both Loadometers were correct to within less than one per cent. Of three trucks on which Loadometers were tried out the results were as follows: Loadometer weights were 11,210 lbs., 15,780 lbs. and 14,540 lbs. Scale weights for same were 11,250 lbs., 15,840 lbs. and 14,660 lbs. The conditions for weighing at the scales were, of course, very good—much better than could be found on the road.

The work was started on San Fernando Road in the vicinity of Newhall Tunnel. Permission was secured from the Board of Supervisors of Los Angeles County for a regular traffic officer to be present with the men at all times to stop trucks and order the driver to submit to the weighing. It was found that this officer could not be dispensed with as truck drivers in general resented being stopped, especially if they were conscious that they carried an overload.

The truck that was to be weighed was first trailed for a short distance, say one quarter of a mile, to obtain the speed at which it was traveling. If there was any variance in speed on curves or up or down a grade this fact was noted. The speed meter of the machine used on the work (a Nash Chummy Roadster) was checked up and found to be correct before work was started. The machine then ran around the truck, going ahead until a comparatively level spot in the road was located. At this point the truck was stopped and the actual weighing took place. One jack was put under the rear axle close to one wheel and the other under the front axle close to the wheel on the same side of the truck as the rear jack. Both jacks were raised at the same time and their readings recorded. The distance was measured from the center of the tire on the opposite side of the truck to the point at which the jack was applied and also the entire distance between the centers of the two tires for each axle separately. Let S equal the total distance from center to center of tires; s equal the distance from the center of the tire opposite the point at which the jack was applied; L equal the jack reading; W equal the total weight. From these quantities and the use of the formula $W=\frac{2\ Ls}{S}$ the loads carried on the axle were determined. Each axle is thus separately weighed. The sum of the two results gave the total gross weight of the truck.

In order that the results from the above method be absolutely correct, the road must be level transversely; the load must ride evenly between the wheels; and it must be a load that will not shift when one side of the truck is raised as with high loads. The results obtained, however, are reasonably correct. In no case were they farther than 4% from correct, the average error being 2.50% for the trucks checked on standard scales.

The method and results previously described were used because the work had to be done with reasonable accuracy in the shortest possible time. Greater accuracy could be obtained by using the two jacks under the rear axle and determining the weight thereon, the load being very slightly lifted from the pavement. After weighing one end in this manner, both the jacks could then be moved to the front axle which could be weighed in a similar manner. A still more perfect method of weighing loads with loadometers, and one which would entirely remove any feeling of uncertainty on the part of the truck operator or the court, would be to use four jacks, putting one under each wheel and completely lifting the load off the pavement. Under the method first described it took about twenty minutes to weigh a truck.

Other Field Data Taken Relative to Trucks

The number of inches of the tires in contact with the road as well as the manufacturer's rating thereof in inches was noted for comparison with the Vehicle Act which fixes a maximum of "800 lbs. per 1 inch of tire in contact with the road." The condition of the tires was observed. A tire presenting a smooth surface to the road and not too thin to have lost its resiliency was graded good; a tire presenting a rough surface to the road but still retaining its resiliency was called fair; one which was worn down so thin that it had lost all resiliency or which was so cut and torn as to be of insufficient width to support its load was called poor.

The character of the load was recorded as well as the type of the body used. The kind of drive, whether chain or gear, was noted. The distance was measured from the center of gravity of the load to both the front and the rear axle. A load of oil-well casing is distributed on its wheel base in a manner differing from a load of pig iron on a similar truck.

The license number and name of owner of the truck were taken and measurements were made of the spread of the tire under its load by placing pieces of clean paper on the pavement. The truck was then driven over them. The width of the track was then compared with that of the tire not in contact. The results varied widely, depending on the make and quality of the rubber. The greatest spread encountered on any old tire was 3/8 inches for a 7-inch tire under a large load. The average spread on all old solid tires is about 1/4 inch.

One hundred ninety-two trucks were weighed and the other data obtained regarding them. These are representative of all classes of loaded trucks traveling on the State and County roads.

Tables No. 16 and No. 17, pages 60-62, are self explanatory and are in fair agreement with the information compiled from data obtained by weighings on the public scales. These records are not included in the previous tables.

TABLE NO. 16

OVERLOADS CARRIED BY TRUCKS WEIGHED ON THE ROAD WITH LOADOMETERS

Comparison With Legal Loading

	Rated Capacity of Trucks in Tons										
	1	1½	2	2½	3	3½	4	5	5½	6	
1. No. of trucks under capacity	3	4	10	2	2	3	3	3	...	...	...
2. No. of trucks at capacity	3	1	...	...	2	5	1	2	...	...	...
3. No. of trucks capacity to one ton overload	4	6	8	3	3	6	3	5	...	...	...
4. No. of trucks one to two tons overload	...	4	8	1	5	9	2	10	3	1	...
5. No. of trucks two to three tons overload	...	2	9	...	2	9	2	11	1	...	...
6. No. of trucks three to four tons overload	...	1	3	...	1	2	...	12	...	...	...
7. No. of trucks over four tons overload	...	...	...	...	...	...	...	9	1	2	...
Total Number of Trucks	10	18	38	6	15	34	11	52	5	3	192

3-7 Extensive longitudinal cracking south of San Juan Capistrano, Orange County. Soil, adobe. No shoulders. Pavements in this condition are classed as poor and require reconstruction.

Caterpillar using highway, San Diego County. Note tracks on road.

Table No. 17

DATA COLLECTED REGARDING 192 TRUCKS WEIGHED AT RANDOM ON COUNTY AND STATE HIGHWAYS WITH LOADOMETERS

	Rated Capacity of Truck	1 T	1½ T	2 T	2½ T	3 T	3½ T	4 T	5 T	5½ T	6 T
1.	Gross Weights: Total pounds	65,807	223,170	556,416	84,103	279,980	713,775	226,960	1,287,169	141,501	103,002
2.	Gross Weights: No. of trucks	10	18	38	6	15	34	11	52	5	3
3.	Gross Weights: Average pounds	6,580	12,398	14,643	14,017	18,665	20,993	20,663	24,753	28,300	34,334
4.	Gross Weights: Maximum pounds	8,655	20,390	19,830	17,890	23,475	24,940	26,275	30,665	30,275	44,292
5.	Per cent of trucks using highways	All	All	All	All	All	All	All	All	All	All
6.	Average concentration of load on one rear wheel in lbs.	2,440	4,564	5,636	5,132	7,028	7,930	7,809	9,736	10,624	13,088
7.	Average allowable load on one rear wheel in lbs. (State law)	2,320	3,717	4,653	4,800	5,880	6,700	7,382	7,346	8,360	8,400
8.	Maximum concentration of load on one rear wheel in lbs.	3,450	8,150	8,000	6,125	9,500	10,040	9,825	12,804	11,650	17,916
9.	Average concentration of load one front wheel in lbs.	850	1,634	1,694	1,875	2,304	2,566	2,502	2,640	3,526	4,075
10.	Average allowable load for one front wheel in lbs. (State law)	Air Tires	2,217	2,289	2,866	2,866	2,988	3,164	3,427	3,640	3,866
11.	Maximum concentration of load one front wheel in lbs.	1,057	2,580	3,515	2,820	4,250	5,425	3,312	3,650	4,437	5,300
12.	Average per cent of load carried on rear axle	74%	73%	77%	73%	75%	75½%	76%	79%	75%	76%
13.	Average per cent of load carried on front axle	26%	27%	23%	27%	25%	24½%	24%	21%	25%	24%
14.	Average speed in miles per hour	18.4	19.6	17.6	16.5	14.75	15.5	15.5	15	13	13
15.	Maximum speed in miles per hour	22	22	22	22	18	21	19	21	15	14
16.	Average concentration of load per 1″ of tire on road—rear—in lbs.	861	991	963	803	945	970	853	1,074	1,045	1,216
17.	Maximum concentration of load per 1″ of tire on road—rear—in lbs.	1,149	1,211	1,362	1,070	1,266	1,239	1,103	1,424	1,225	1,560
18.	Average concentration of load per 1″ of tire on road—front—in lbs.	Air Tires	596	591	547	651	697	634	616	842	823
19.	Maximum concentration of load per 1″ of tire on road—front—in lbs.		938	1,082	868	1,132	1,207	770	868	990	1,008
20.	Average widths of rear tires in inches	3″	4.55″	5.76″	6.0″	7.50″	8.39″	9.23″	9.18″	10.66″	10.60″
21.	Per cent of trucks with poor tires	20%	33%	34%	33%	13%	41%	10%	29%	0	100%
22.	Per cent of overloaded trucks rear end based on 800 lbs. per 1″ of tire on road	70%	83%	73%	66%	73%	76%	73%	92%	100%	100%
23.	Average overload per 1″ tire on road (800 lbs. per 1″) rear in lbs.	61	191	163	3	145	170	53	274	245	416
24.	Maximum overload per 1″ tire on road (800 lbs. per 1″) rear in lbs.	349	411	562	270	466	439	303	624	425	760

Engineering Offices of
J. B. LIPPINCOTT
Sept.-Oct., 1920

The State of California has now voted \$73,000,000 for the building of good roads and the counties \$42,000,000 more, a total of \$115,000,000. Over half of this immense sum has been expended. The inspection that has been made of the State roads in Southern California shows that today thirty per cent of the pavements are in poor condition with an average age of pavement of 4.24 years. Probably ten million dollars' worth of State and county pavements in Southern California have failed.

While it must be admitted that these pavements have been too narrow and too frail and often foundation conditions were defective, it is also certain that a large portion of these failures have been caused by excessive and illegal overloading of the slab.

Table No. 17, page 62, reveals that 70% of the 1-ton trucks, weighed on the country roads, were loaded in excess of the legal limit, that 92% of the 5-ton trucks, 100% of the 5½-ton trucks and 100% of the 6-ton trucks carried illegal loads. The State law limits the load to 800 pounds per inch of width of tire in contact with the road. The 192 trucks weighed on the country roads show that the average overload on a 1-ton truck was 61 pounds per inch of tire while the average overload of the 1½-ton trucks was 191 pounds, 2-ton trucks 163 pounds, 3-ton trucks 145 pounds, 5-ton trucks 274 pounds, 5½-ton trucks 245 pounds and the 6-ton trucks 416 pounds. The maximum concentration of load per inch of tire on the road with these trucks ran as high as 1,560 pounds, with a maximum total load on one rear wheel of 17,916 pounds.

As shown in Table No. 15, page 56, 500 trucks were weighed on the public scales in the City of Los Angeles and much the same results were obtained for the town trucks as were found for those in use out on the country highways. The table shows that 75% of the 1-ton trucks were overloaded, 60% of the 2-ton trucks, 75% of the 3-ton trucks, 84% of the 4-ton trucks and 67% of the 5-ton trucks. Based on comparison with the loads allowed by law, the average overloads per one inch width of rear tire of the trucks weighed in town as compared with the State's 800-pound limitation were as follows: 1-ton trucks 259 pounds; 2-ton trucks 257 pounds; 3-ton trucks 109 pounds; 3½-ton trucks 345 pounds; 4-ton trucks 313 pounds; 5-ton trucks 292 pounds. The maximum overloading per one-inch width of tire as compared with the State law was as follows: For 1-ton truck 738 pounds; 2-ton trucks 812 pounds; 2½-ton trucks 720 pounds; 3½-ton trucks 768 pounds; 4-ton trucks 877 pounds and 5-ton trucks 1,040 pounds. The maximum concentration of load on one rear wheel for the larger of these town trucks was as follows: 3-ton trucks 8,925 pounds; 3½-ton trucks 10,960 pounds; 4-ton trucks 10,075 pounds; 5-ton trucks 11,280 pounds. The loads of about 60% of these town trucks originated on or were destined for the State or County highways.

It seems incredible that in the face of such a record of destruction of the State pavements that these persistent, unreasonable and illegal loads should continuously be permitted to traverse our highways. There has been practically no serious attempt made on the part of either State or County authorities to enforce the laws that have been provided by our Legislature for the protection of these roads. A very few and far scattered arrests have been made, but as far as known but one case has been carried as far as the County Superior Court of the State and in this instance a decision was rendered in favor of the prosecution, in Alameda County. The law to the layman seems perfectly clear and capable of enforcement. The truck dealers and manufacturers, as a rule, are opposed to the overloading of these trucks and advise against it. There are, however, some notable exceptions where truck advertisements have been issued by dealers which would justify prosecution.

There is a pronounced tendency to increase the size and capacity of trucks because the cost per ton mile of hauling large loads is less than for small. The 7½-ton truck has made its appearance on our highways. The field inspections clearly show that our roads already are breaking down under excessive weights and any increase in such loads should be strongly resisted by all those who are interested in the preservation of our highways. It really is

to the interest of both the truck dealer and the operator to keep these loads within reasonable limitations, otherwise they will bring down upon themselves restrictions under the law which are apt to be unreasonable, to say nothing of the breaking down of the highway which is essential to their existence. The careful study of the Committee on Slab Construction, which is attached to this report, finds that the maximum load on any wheel, within reasonable limits of the width of tire, is a controlling factor in determining the necessary thickness of the slab or in breaking down existing slabs. No load in excess of 10,000 pounds should be allowed on any one wheel.

The effect of pneumatic tires on the pavement has been demonstrated to be less injurious when heavily loaded than in the case of solid tires. It follows that the use of the pneumatic tires should be encouraged by the law both in increasing the speed limit for loaded trucks having pneumatic tires and possibly by reducing the license fee on trucks using such tires. Such a provision has been recommended in the Uniform Motor Vehicle Law which is referred to in the report of the Committee on Trucks and Truck Laws.

The hauling of freight in trucks on improved highways is a new economic development of great value to the community at large as well as to the truck owners. It has greatly enhanced the efficiency both of farmers, manufacturers and merchants in the distribution of their products. This business should be fostered and encouraged. Any attempt to radically reduce the legal loads or speeds probably would result in defeat. These trucks are inter-county and to a limited extent inter-state in their operation. Their load should not be regulated by a great variety of differing county or state laws. The situation is being met by those interested in the trucking business by the presentation of a National Uniform Motor Vehicle Law to apply throughout the United States. This law is closely in harmony with the existing California laws. There appears no reason why the portions of this law relative to weights should not be adopted by California with a single limitation that not over 10,000 pounds should be allowed on any one wheel on the California highways because they are not built so as to hold up under any greater loads. See Committee Report on Laws.

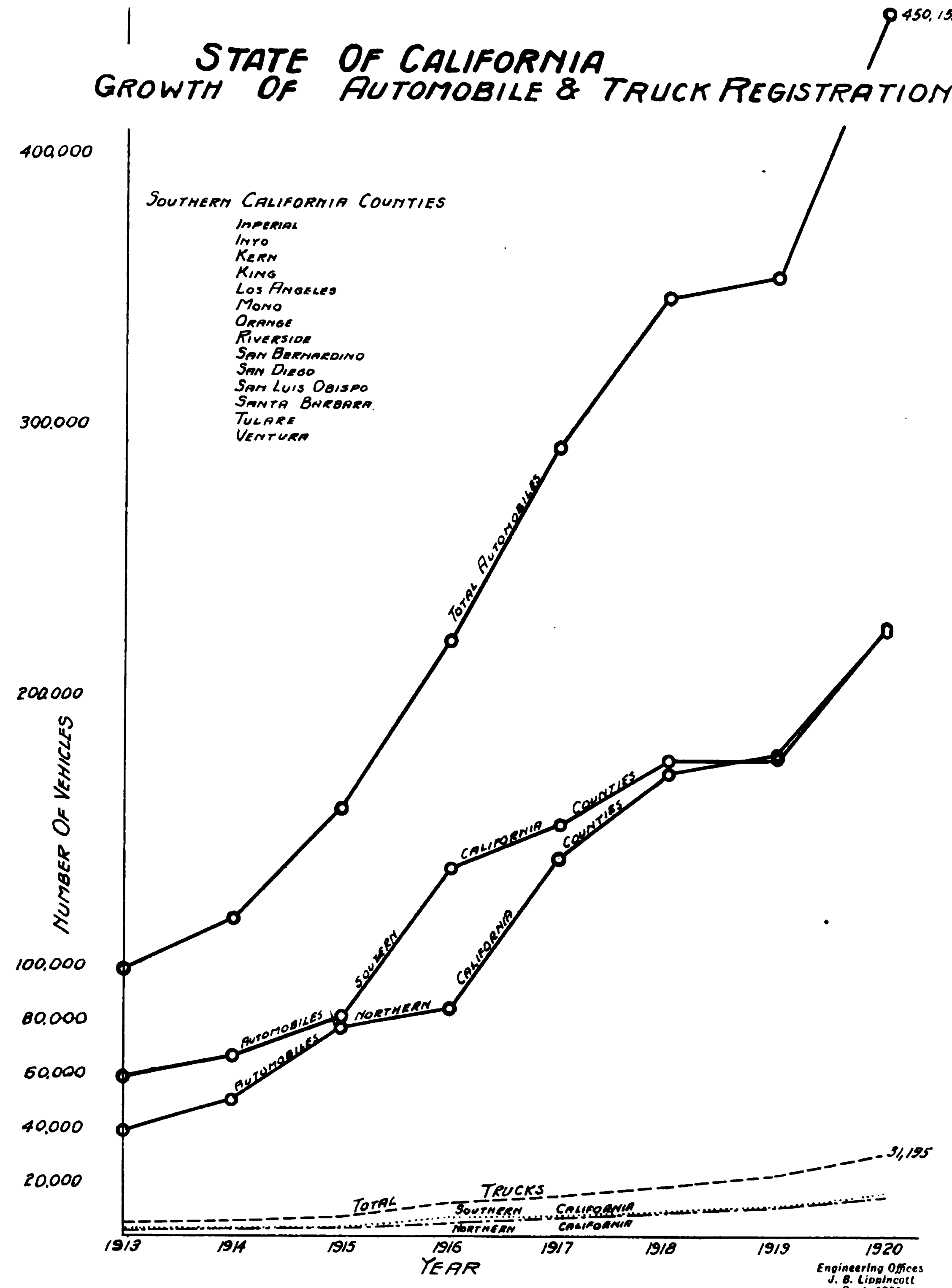
The State and County authorities allege that it is difficult for them to enforce the existing law because arrested parties are brought before Justice Courts where local influences interfere with convictions. In at least one case successful appeals have been made to the County Superior Court. It is outside of the scope of an engineering report to discuss legal procedure, but it is suggested that if possible there should be some State authority devoid of local influence made available for the prosecution of those who flagrantly violate these traffic laws thus causing enormous financial loss to the people of California as well as interfering with the legitimate use of the highway. It cannot be too strongly stated that unless some enforcement of reasonable laws with reference to the use of the public highways can be accomplished that our bridges and pavements will continue to be destroyed at an alarming rate. Our inspectors find that the presumptive life of our California pavements under present traffic will not be over 15 years.

Growth in Numbers of Automobiles and Trucks in California

Rapid growth in the utilization of motor vehicles has developed in the last decade. Following the building of hard surfaced roads by the State and counties, the growth in number of vehicles was tremendous. Diagram No. 6, page 65, shows in 1913 a total of 103,698 motor vehicles were registered and on July 1, 1920, 481,350 autos and trucks were licensed—a growth of 464% in 8 years.

Out of 58 counties in the State, the 14 counties in the territory of the Automobile Club of Southern California in 1913 had 63% of the auto and truck registration and in 1920 these same counties had 50% thereof.

Diagram No. 6



STATE OF CALIFORNIA
GROWTH OF AUTOMOBILE & TRUCK REGISTRATION
450,155
400,000
300,000
200,000
100,000
80,000
60,000
40,000
20,000
NUMBER OF VEHICLES
SOUTHERN CALIFORNIA COUNTIES
IMPERIAL
INYO
KERN
KING
LOS ANGELES
MONO
ORANGE
RIVERSIDE
SAN BERNARDINO
SAN DIEGO
SAN LUIS OBISPO
SANTA BARBARA
TULARE
VENTURA
TOTAL AUTOMOBILES
SOUTHERN CALIFORNIA COUNTIES
AUTOMOBILES
NORTHERN CALIFORNIA COUNTIES
AUTOMOBILES
TOTAL TRUCKS
31,195
SOUTHERN CALIFORNIA
NORTHERN CALIFORNIA
1913
1914
1915
1916
1917
1918
1919
1920
YEAR
Engineering Offices
J. B. Lippincott
Sept. 1920

REPORT OF THE COMMITTEE ON MAINTENANCE

Mr. George Jones, Chairman, Road Commissioner, Los Angeles County.
Mr. E. E. East, Road Engineer.
Mr. S. H. Finley, Supervisor, Orange County.

MAINTENANCE

Time is the most essential factor in determining the relative values of various types of pavements. The first cost is not the only one attached thereto, much propaganda circulated prior to bond elections to the contrary notwithstanding. There is no such thing as a permanent pavement.

Complete and reliable data as to the cost of maintaining highways in the United States is rare. This can largely be explained in that Highway Engineers have been busy developing types and in raising money for construction and there has been little time devoted to investigating the cost of upkeep. The life of our present day highways has been too short to permit little more than a rough indication of what the total upkeep is.

This study may be divided into two parts. First, an investigation dealing with the actual total upkeep to date, and second, the estimated total cost over a period of years.

The major portion of the report deals with the State Highways of Southern California. Los Angeles County oiled macadam and concrete, and Orange County concrete roads have been investigated and data compiled as to their first cost and upkeep.

The terms used in the discussion are here defined as follows:

General Maintenance:

Minor repairs to pavement and oil surface, repairs to guard rail, mowing weeds, grading in shoulders, drainage, etc.

Upkeep:

Includes reconstruction, resurfacing, additions, and general maintenance.

Fixed Charges:

Interest and bond retirement fund applied to original cost of road.

Average Weighted Age:

This is the quotient of the sum of the miles, times their respective age, divided by the total miles.

Overhead:

Includes both Headquarters, Division administration and supervision, undistributed charges, compensation insurance, repairs to equipment, etc. This amounts to approximately 20%.

A knowledge of the life of a pavement is essential to the determination of its economic value.

The inspection of 602 miles of State Highway, with an average weighted age of 4.24 years, disclosed that 50.2% were good, 19.3% fair and 30.5% poor. Some 32 miles of this pavement have been resurfaced with either concrete or a heavy bituminous carpet at a cost in excess of that of the original pavement. The average weighted age of this resurfaced pavement is 4.3 years.

Tabulating the roads according to years built and noting the per cent of failure to July, 1920, an indicated life of roads built during each of the years 1913 to 1919 was obtained. From this an average weighted life of 14.69 years was found for the 602 miles. Table No. 19, page 79.

Frederick Stuart Greene, Commissioner of New York State Highways, writing in Engineering News Record of August 21, 1919, in discussing the relative merits of concrete and macadam pavements finds that "it is conservative to suppose that the concrete pavements as now laid will last 15 years" and also that the average life of a macadam pavement to the point at which re-

Breaking down of concrete at contraction joints near San Bernardino, San Bernardino County.

9-8 Destruction of oil surface by heavy steel-tired traffic, Ventura County.

surfacing is required has been found in New York State to be 7 years. The concrete pavements referred to are 8 inches in thickness at center and 6 inches at edge.

J. N. Mackall, Chief Engineer of the Maryland Highway Commission, in the Engineering News Record of May 6, 1920, page 914, states that in his opinion 10 years may be taken as the life of a concrete pavement under heavy traffic and from 15 to 20 years for the light traffic pavements. The Maryland concrete pavements are 8 inches thick at the center and 6 inches at edge.

In view of the above, 15 years has been taken as the average life of the California 4-inch concrete pavements. Where subjected to the same conditions, the various county concrete pavements are found to be in much the same condition as the state pavements.

The life of a bituminous pavement, and by such is meant all pavements in which bitumen is used as the binder, is indeterminate in that it may be resurfaced, or scarified and renewed at any period and thus maintain the essential qualities of the pavement.

A concrete pavement has reached the limit of its life as such when it becomes necessary to patch its surface due to deterioration.

A worn out concrete pavement, surfaced with a bituminous mixture has to a large extent lost its characteristic as a rigid pavement and may be classed as non-rigid. It is upon the above assumption as to life that deductions beyond the year 1920 are made.

In considering the cost of maintaining the state highways in Southern California, all expenditures of whatever nature, excepting the first application of ⅜-inch oil surfacing, made after the final acceptance of the road by the Commission, are classed as Maintenance and Upkeep. Many expenditures have been made which are for additions and betterments. They are all necessary for the continued use of the road and constitute an annual expense that is practically continuous in its occurrence. Illustrating this point, on the Ventura Road a storm drain was constructed in 1919 at a cost of $9,319.00. This may not be strictly speaking a Maintenance charge but it represents a cost which will recur throughout the system. Had it not been built the probability is that a much larger sum would have had to be expended in replacing embankment and washed out pavement.

Much difference in opinion exists relative to the classification of the various expenses incurred in the upkeep of pavements. However, in this study consideration must be given to the sources from which revenues are obtained. The original construction is financed from the sale of bonds which bear an annual interest and are retired at given periods. The revenue for upkeep is provided from direct tax. Any reconstruction work charged to the construction fund would, therefore, incur fixed charges.

It was expected that the general maintenance charge would be a constantly increasing figure. This, however, is found to vary, partly due to storm damage and largely with the amount of money available. The section of road west of Universal City, designated as L. A. 2-A, was opened to traffic in January, 1914. During the period 1914 to 1919 inclusive the General Maintenance Charge proper was as follows: 1914—$500.00; 1915—$1,028.00; 1916—$2,280.00; 1917—$857.00; 1918—$836.00; 1919—$2,478.00, exclusive of overhead.

In the early part of 1920, 5.23 miles of this section were rebuilt at a total expense of $74,751.00 or an average of $14,293.00 per mile. During the first half of 1920 the General Maintenance on this section (6.55 miles) has been $209.00 or at the rate of $418.00 per year. Probably the larger part of this expense has been incurred on the remaining portion of the original road, viz., 1.32 miles.

That portion of the State Highway leading from San Fernando to Pasadena, a length of 15 miles, was built under two separate contracts. The first 4.90 miles was opened to traffic in March, 1916. The second portion in January, 1919. The general maintenance, exclusive of overhead, of this road has been as follows: 1916—$139.00; 1917—$264.00; 1918—$416.00; 1919—$704.00; to July, 1920—$666.00. This shows a steadily increasing maintenance charge over the

Longitudinal cracks through cut, mile 11.2 north of Castaic School, "Ridge Route," Los Angeles County. This pavement is but one year old and was built on a road-bed four years old. The probable explanation is poor concrete.

Longitudinal cracks, mile 12.2 north of Castaic School, "Ridge Route," Los Angeles County.

L. A. 2-C Mile 2.9 west of Calabasas, showing disintegration of pavement 450 sq. ft. in area.

L. A. 2-C Mile 2.9 west of Calabasas, showing disintegration of pavement 450 sq. ft. in area.

period. For an average weighted age of 2.35 years this upkeep cost has been \$62.00 per year mile. This is one of the light traffic roads on good soil. It is expected that its life as a concrete road will be much longer than that of the heavy duty roads.

One of the first roads built in Southern California by the State is just north of the city limits of San Diego, designated as San Diego 2-A. This road was opened to traffic in the latter part of the year 1913. The maintenance by year on this 8.58 miles has been as follows: 1914—\$192.00; 1915—\$3,092.00; 1916—\$4,256.00; 1917—\$1,537.00; 1918—\$2,275.00; 1919—\$1,653.00; first half of 1920—\$839.00. This section has had an average age of 7.40 years and is classed as 1.2 miles good, 4.2 miles fair and 3 miles poor in 1920.

The annual upkeep costs on oil macadam pavements are more constant. A slight increase is noted at stated intervals, occasioned by renewal of wearing surface.

If upkeep costs had been found to increase in a somewhat uniform ratio, the economic life of a given road could be readily determined.

The general maintenance charges for state roads have been assembled for purposes of study and comparison from data furnished by the Highway Commission, twenty per cent having been added to cover overhead, undistributed charges, repair to equipment, etc., by this authority. No item has been included covering maintenance grounds and buildings. If modifications of results are to be made it will probably increase the totals. These items include only that class of upkeep work known as General Maintenance, such as is usually done by the regular repair crews stationed on a section, making minor repairs to concrete base, and oil surface, replacing guard rail, mowing weeds, grading in shoulders, ditching, etc. There is shown an average annual expenditure for this class of work for 626 miles (including Inyo County) of \$285.00 per mile or \$0.0315 per sq. yd. for an average weighted age of 4.45 years. Deducting 78 miles, which includes mountain roads maintained for a period as oiled dirt roads, 1½ miles of timber trestles in Ventura County and the plank road, an average of \$235.00 per mile or \$0.0263 per sq. yd. per year is obtained for an average weighted age of 4.38 years. The maintenance annually for the 78 miles is \$598.00 per mile and \$0.0607 per sq. yd. per year for an average weighted age of 4.94 years.

Similar maintenance cost on 26.09 miles of 5″ concrete roads built by Los Angeles County and 8.67 miles of 4″ concrete road built by San Bernardino County, including overhead and incidentals, indicates an annual cost for 34.76 miles of \$138.00 a mile or \$0.0122 per sq. yd. for an average weighted age of 3.28 years.

The tonnage carried by these county concrete roads is much less than for state roads and the average age is also less.

The expenditure for maintenance and upkeep for the 626 miles of state roads from 1912 to July, 1920, including reconstruction, resurfacing and widening, per mile year, to July, 1920, has been \$615.00 or \$0.0678 a sq. yd. for an average weighted age of 4.45 years. Adding to this average annual interest and bond retirement payments on a total first cost of \$11,340,408, gives an average annual total charge of \$1,353.00 per mile or \$0.149 per sq. yd. This is summarized as follows: General maintenance \$285.00; reconstruction \$175.00; resurfacing and widening \$155.00; average interest \$390.00; average retirement fund \$348.00; total \$1,353.00, all per year mile.

The various items of maintenance for 96.75 miles of oiled macadam pavements built by Los Angeles County, including overhead and all items chargeable to maintenance, for an average weighted age of 7.88 years, have been annually: For reconstruction, \$121.00 per mile or \$0.0098 sq. yd.; widening and resurfacing, \$380.00 per mile, or \$0.0315 sq. yd.; general maintenance, \$382.00 per mile or \$0.0314 sq. yd.; total for upkeep \$883.00 per mile or \$0.0727 sq. yd. Adding average annual interest and bond retirement payments on 40-year serial bonds gives a total charge of \$1,611.00 a mile or \$0.1337 a sq. yd. per annum.

Maintenance and upkeep cost for 137 miles of Orange County concrete roads, for an average weighted age of 4.16 years, has been $164.00 per year mile or $0.0160 sq. yd. year. This includes overhead. Several miles of these roads will be surfaced in the near future.

The following comparative data has been compiled:

Table No. 18

Upkeep Cost of Concrete Roads

Miles	Av. Age	Upkeep	Av. Annual	Year Mile	Sq. Yd. Year
		State			
626.62	4.45	$1,713,717.00	$385.104.00	$615.00	$0.0678
		Los Angeles County			
34.76	3.28	$15,647.00	$4,770.00	$138.00	$0.0122
		Orange County			
137.24	4.16	$93,538.00	$22,485.00	$164.00	$0.0160

The upkeep for Los Angeles County oil macadam roads is as follows:

96.75	7.88	$672,669.00	$85,364.00	$883.00	$0.0727

The average total cost, including fixed charges per mile of the oil macadam pavements, is greater, while the square yard cost is less than the corresponding figures for the State concrete roads. This is due to the greater width of the macadam roads and the lesser first cost on which fixed costs are based.

The average first cost per mile for 626 miles of State concrete roads has been $18,097.00 against an average cost of $14,374.00 per mile for the 96.75 miles of macadam roads.

The total bond issues out of which the 626 miles of state roads have been built will be retired in 1962, while the County issue will be retired in 1949. The fixed charges on the State roads which amount to $738.00 per year mile will continue to 1962. This same fixed charge on the Los Angeles County macadam roads amounts to $728.00 per year mile and will continue to 1949.

The average annual tonnage for 502.22 miles of State roads has been 634,000 tons against an average annual tonnage for 107.39 miles of macadam roads of 1,230,000 tons. Expressed in ton miles for upkeep, exclusive of fixed charges, this is $0.00129 for State concrete roads and $0.00072 for county oil macadam.

Table No. 18-A

Comparative Tabulation of Annual Upkeep Costs Expressed in Ton Miles

Miles	Yr. Age	Total Upkeep	Yr. Mile	Av. Annual Tonnage	Upkeep Ton Mile
		State Roads (Concrete)			
502.22	4.54	$346,945.00	$690.00	634,000	$0.00129
		County (Oil Macadam)			
107.39	7.02	$11,870.00	$884.00	1,227,685	$0.00072

The upkeep costs per ton mile are not in direct proportion to tonnage carried. In San Bernardino County, State Route 9 Section A, the tonnage is 876,000 tons per year. Expressed in ton miles upkeep this is $0.00029. Kern 2-F, a State concrete road, shows a ton mile upkeep charge of $0.00129 for an annual tonnage of 565,750. The average age in each case is approximately the same. Adjacent sections carrying the same tonnage show widely different costs.

The Foothill Boulevard, an oil macadam pavement, carrying the same annual tonnage as San Bernardino 9-A, cost $0.00034 per ton mile for upkeep for an average age of 8.00 years.

The Whittier oil macadam road over the same period has carried 2,153,500 tons at an annual upkeep charge of $0.00029 per ton mile.

The El Monte oil macadam boulevard over a 7-year period has carried 1,657,100 tons per year at an annual cost of $0.00099 ton mile.

22-7 View of oil macadam road, Foothill Boulevard, Glendora-Lordsburg. Laid on soil with good drainage. Traffic heavy.

22-8 View of Foothill Boulevard, oil macadam pavement, Azusa-Glendora. Laid on soil with good drainage. Traffic heavy.

The oil macadam pavements have carried approximately twice the annual tonnage at a less cost per ton mile for upkeep and have also been in service 7.02 years against 4.54 years for the State concrete roads considered on this basis. Further, thirty per cent of the concrete roads are classed as poor, and must soon be rebuilt, while the macadam roads are classed as good.

The year 1916 may be taken, for the purposes of further analysis, as the average date of completion for the 626 miles of State road under consideration. The bonds with which these 626 miles of State roads were built will all be retired in 46 years thereafter.

On the assumption of an average life of pavement of 15 years, provision must be made for renewal at the end of the first fifteen years and a second renewal prior to 1962. Allowing $15,000 per mile for pavement for each renewal and assuming that the average annual general maintenance charge of $285.00 per mile will be continuous over this period, the cost of one mile of road in 1962 would be $30,000.00 plus the annual maintenance of $285.00 for 46 years plus annual interest and bond retirement for the original road of $77,058.00. This gives a total average annual charge of $1,674.00 per mile for 46 years of service.

On the foregoing assumption, the original concrete roads have now become a foundation for either a bituminous surface or a new concrete surface as the case may be. The value of this original road as a foundation is indefinite. If it has failed as a wearing surface, will it not continue to fail as a foundation? Inspection made of various roads which have been resurfaced with a Topeka top shows that this deterioration found in the original road is continuing. For example, on that portion of the State concrete highway which has been surfaced with 1½-inch of Topeka top between Pomona and Ontario, known as San Bernardino 19-A, several points are found where the surface of the road is depressed and the Topeka surface is pushing up and disintegrating. This is caused by continued failure in the 4-inch concrete base. Photograph No. 21-5, shows this condition. The Ventura road just west of Universal City has recently been resurfaced with 1½-inch Topeka. This surface shows signs of foundation movement.

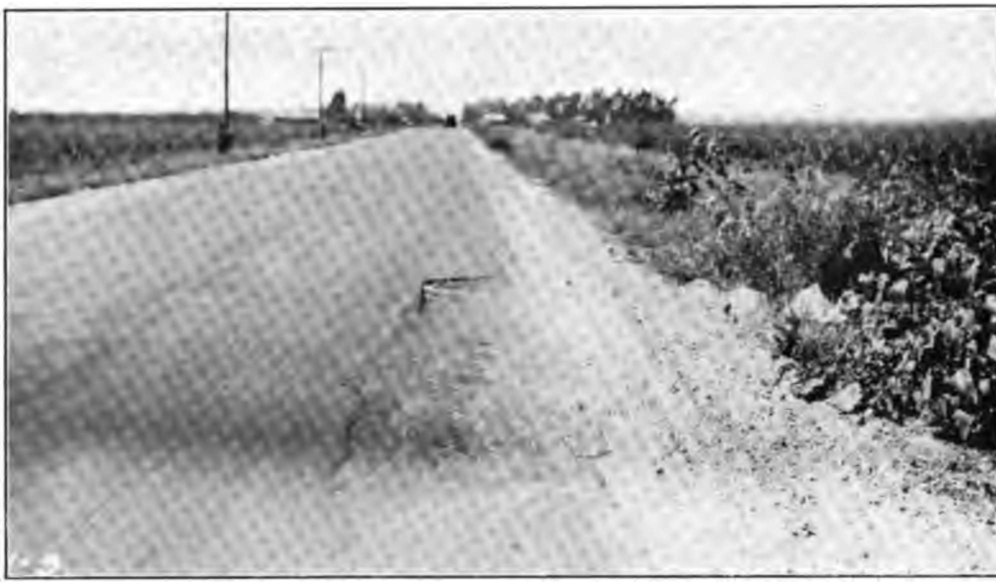
The above deductions made beyond the year 1920 are subject to criticism and they are given only as a rough means of estimating the cost to the taxpayers of maintaining a mile of improved highway.

Referring again to the oil macadam roads built by Los Angeles County for the purpose of extending the analysis and comparison, it is estimated, based on general conditions of these roads today, that the upkeep and fixed charge will be $1,611.00 per mile including interest and sinking fund. This will carry these roads to the limit of the life of the bonds, which is 1949. At this time the total cost per mile, on the above reasoning, will be $62,413.00.

From 1949 to 1962, a period of thirteen years, the total upkeep cost will be $883.00 per year mile, giving a total cost of this road in 1962 of $73,892.00.

The people of California will continue to insist on good roads. There were, June 30, 1920, 450,000 automobiles and 31,000 trucks in California using these roads. The pleasure and economic value of this system of highways has been thoroughly established. The conclusion to be drawn from this study is that we should build better roads with longer life and that they should be protected against abusive use. While long-lived bonds may properly be used for grading highways and building permanent structures, shorter lived bonds should be voted for building pavements or they should be constructed from direct taxation. While the oil macadam types of road from the basis of actual cost are shown to be no more expensive than 4-inch concrete pavements, the concrete pavement has become the one most universally used for the construction of state highways in the United States. Due consideration should be given to the source from which money is obtained for the upkeep of the ever-growing mileage of improved highways and the traffic that is developing thereon.

The total length of State roads proposed under the three bond issues is approximately 5,600 miles. If this total mileage is built with similar pavements to the past, the annual charge



Showing failure in pavement repaired with oil macadam south of Tustin, Orange County.

Showing failure of oil macadam shoulder south of Tustin, Orange County.

Rutting of Topeka surface south of Fresno, Fresno County.

New oil surface 7.2 miles east of Hanford, Kings County.

for upkeep, interest and sinking fund will amount to approximately $11,000,000.00. At the present time there are some 3,300 miles of paved county roads in California. Adding to this the 5,600 miles of State highways built and proposed, gives a total of 8,900 miles of paved roads. These roads in general have been built through the sale of bonds. Aside from this there are approximately 60,000 miles of unimproved roads which call for their proportionate part of maintenance. The total cost of this large mileage of improved and unimproved roads may easily amount to twenty millions of dollars annually. This demonstrates the great importance of this road problem to the people of California.

The usual argument advanced in favor of hard surfaced roads is that the maintenance of earth roads or gravel roads far exceeds that of the hard surfaced roads. This assertion is made, it appears, without due consideration for what has been done in other states with this type of road.

In the Engineering News Record of December 9, 1915, page 1110, it is noted that the Department of Highways of New Hampshire has improved and maintained by direct tax a system of approximately one thousand miles of gravel roads for a period of three years at an average annual cost of $250.00 per mile. The excellence of these New Hampshire gravel roads is vouched for by the many tourists who travel through this state. Traffic on many of these roads averaged from eight hundred to one thousand cars per day, a maximum for one day of fifteen hundred automobiles was noted.

The Engineering News Record of December 19, 1918, states the maintenance of Wisconsin's gravel roads was $125.00 per mile per year.

The maintenance of the Michigan gravel roads is from one hundred to three hundred dollars per year mile. (Engineering News Record of October 11, 1917.)

The State of Indiana has for many years been developing an excellent system of gravel roads by direct tax. At the present time approximately every city in the State may be reached at any period of the year over one of them. No information is available as to the annual maintenance charge.

In the Engineering News Record of November 11, 1920, it is noted that Michigan is building some hundreds of miles of trunk line gravel roads. "With 6,000 miles of trunk line highways, it is held humanly impossible for some years to hard surface all the mileage even if present traffic warranted hard surface."

"Excellent gravel road construction, maintenance and service is the vivid impression of Michigan Highway practice in 1920. A conservative hard surfacing program covering main traffic routes and highways tributary to industrial centers is being developed without seeking extensive mileage and with liberality in type of construction employed."

It is recognized that the maintenance of a gravel road is much aided in the Eastern and Middle Western States by climatic conditions. Periodic rains aid in compacting the roads. This condition in California is found only during the winter months. However, the difference between annual maintenance costs shown would outweigh this natural deficiency on many of our proposed roads.

To July 3, 1920, there had been paid in interest and bond retirement fund on the First and Second State Highway Bond Issues the sum of $10,009,000.00 and but $1,600,000.00 in bonds have been retired.

The only justification for the construction of a highway with the proceeds from the sale of long life bonds is when the money is spent in permanent improvements. Future generations should not be required to pay for an improvement the greater portion of which is quickly worn out.

Inasmuch as no type of pavement has been found to date that can withstand modern traffic requirements for a long time, the only portion of a highway that can be constructed on sound financial basis through the sale of long life bonds is the permanent portion of the

16-4 Pavement badly cracked along edge south of Los Cruces, Santa Barbara County. Characteristic on adobe soil.

View of road north of Goleta, Santa Barbara County. Note viaduct in distance.

road, such as grading, bridges and drainage structures. The surfacing of the road, whether of gravel, macadam or concrete or any of the other standard types, should be paid for from current receipts.

An added advantage of this method of financing is that pavements may be built to meet changing traffic conditions of the future. In the meantime the graded portion of the road is serving the needs of the community and at the same time is becoming thoroughly compacted, weak spots are developed and corrected and in general the road-bed is becoming more perfect year by year for the application of any subsequently chosen type of surfacing. Michigan is at the present time experimenting with these gravel roads as a foundation for a bituminous surface. It is believed that after several years of such maintenance an excellent foundation has been obtained.

Many miles of concrete road in California have been built and proposed in districts where materials must be transported at a great expense. Some of these roads have been cut through mountains of natural road surfacing material. Traffic on these roads in some cases is light. If this local material is used for surfacing in place of concrete the annual fixed charges and upkeep expense would be materially reduced, and at the same time an excellent road provided to meet traffic demands.

A continuation of the policy of building so large a mileage of frail hard surfaced roads, the life of which is short, from the proceeds of the sale of long term bonds, will ultimately embarrass the State or break down its good road program. California demands better roads, of longer life, properly financed. The economic development of the state depends on its good roads.

One-half of the net revenues derived from the Motor Vehicle tax were primarily and fundamentally assigned to the California Highway Commission for the purpose of maintaining roads that already had been constructed. From the figures that have been presented, it is plain that all this fund will be urgently needed for this purpose. It should be jealously guarded and applied to this maintenance and reconstruction work alone and not be diverted to construction of new roads or to the carrying of general overhead charges.

(Signed) GEORGE JONES,
Road Commissioner Los Angeles Co.,
Chairman.
E. E. EAST, Road Engineer.
S. H. FINLEY, Supervisor Orange County.

Table No. 19

TABLE SHOWING LIFE, CONDITION AND COMPUTED TOTAL LIFE OF STATE HIGHWAYS IN SOUTHERN CALIFORNIA AS OF 1920

	Total Miles	Years Life	Good	Fair	Poor	Computed Total Life
1913	15.13	7-8	1.30	4.22	9.61	
Percentages			8%	28%	64%	11.7
1914	77.61	6-7	22.57	26.00	29.07	
Percentages			29%	33%	38%	17.1
1915	201.38	5-6	112.78	43.51	45.19	
Percentages			56%	21%	23%	24.0
1916	120.55	4-5	58.96	17.00	44.40	
Percentages			49%	14%	37%	12.2
1917	5.63	3-4	2.14	.89	2.60	
Percentages			38%	16%	46%	7.6
1918	85.63	2-3	39.75	15.19	30.69	
Percentages			46%	18%	36%	7.0
1919	83.61	1-2	52.88	9.27	21.46	
Percentages			63%	12%	25%	6.0
1920	19.82	0-1	9.47			
			10.35	not inspec	ted	
Percentages			100%			
Total	609.36		310.26	116.08	183.02	
Percentages			50.2%	19.3%	30.5%	

Weighted Computed Life.....14.69 yrs.

MAINTENANCE COSTS AND REVENUES

The California Highway Commission has adopted a standard thickness of pavement and has built this practically on all types of soils and under all conditions of traffic. This, in the light of the present inspection, is a mistaken policy. Both the subgrade and the road must be adjusted to meet the condition of both soil and traffic. Soil surveys apparently are an essential feature of road location work and the Division Engineer should be given latitude to vary the type of construction to meet the local conditions which he is in a position to appreciate and which it is difficult to have given proper weight in a highly centralized office.

The report of the Committee on Subgrade and of the Committee on Slab enter into the discussion of the proper method of procedure under these varying conditions. It is recognized by both these committees that economies could be practiced where roads are built on sand and gravel soils, particularly under light traffic, that would be highly improper to practice where the pavement is laid on clay and adobe soils under heavy traffic.

The report of the Committee on Maintenance shows how serious the annual charges are for even the best types of roads under the best conditions.

The fixed charges on that portion of the thirty-three million dollar bond issue, out of which the 626 miles of road under consideration were constructed in Southern California, amounts to $738.00 per mile. The average cost of maintenance, widening and reconstructing the 602 miles of road built by the State in Southern California to date has been $615.00 per mile per year. It has not been feasible to determine the variation between the maintenance cost of roads built on different classes of soil, but it is apparent that the expense has been much greater where the pavement is built on the soils of a clay type.

Of a total of 96.75 miles of oil macadam pavement built by Los Angeles County, the average annual upkeep charge, including general maintenance, reconstruction, resurfacing and widening, has been $883.00 per mile. Some of these roads carry as high as six thousand tons of traffic in 24 hours. They were built on an average 6 inches thick and 20 feet wide under varying conditions of soil. These roads have been constructed and have been in service for an average of 7.88 years, the weight being given to their relative mileage. They were all classified as good at the date of their inspection, July, 1920.

The macadam roads of Los Angeles County under heavy traffic are maintained so that they are generally in good condition. This is accomplished by a continued process of patching with an asphaltic concrete surfacing material or an oil macadam, and the result seems to be a building up of the general character of the road rather than the reducing to an ultimate failure. After a road-bed of this kind has been constructed and in service through a term of years, it offers a foundation upon which either a concrete slab or any type pavement could be laid successfully. This has been done with good success by the County of Los Angeles on the Long Beach Boulevard.

The California Motor Vehicle Act provides license fees for all types of motor vehicles. The revenue derived from this tax was $5,250,000.00 for the fiscal year 1919-1920. According to the existing law, this fund is divided between the counties and the State equally, the result being an annual net revenue from this source to the State of about two and one-half million dollars. The State has constructed to date about 1,332 miles of paved roads. In addition there are 756 miles of unpaved mountain State roads which have to be maintained from this fund as well as 166 miles of paved roads transferred to the State by the counties, a total of 2,255 miles. In addition there are some graded but unpaved roads. On the assumption that two million dollars is distributed over the 2,500 miles of roads now built, the sum available for maintenance would be $800.00 per mile per year. The interest on the highway bonds is derived from the general fund. This revenue derived from the motor vehicle tax should be religiously guarded because of the immense amount of work which will be necessary to maintain our roads under the ever increasing load of traffic. A wise administration of this fund is imperative.

INSPECTION OF ROADS

The most accurate, as well as the most readily understood, test of the pavements that have been constructed in California on various soils and under existing traffic conditions, is the inspection of the pavements themselves as built by the State, by the various county engineers and by corporations. A field study, coupled with the historical data relative to each section, throws light on successful as well as unsuccessful types.

The time that has been allotted for this report is not sufficient to permit of extensive laboratory tests. Especial effort, therefore, has been made to study field conditions. This subject has been approached in the following manner:

A. Filling out, in the field, a standard blank form showing the conditions of sub-base and pavement, for each section or portion thereof.

B. The collection of historical data from the records of the State Highway Commission on standard forms used by the State showing the type and size of pavement, date constructed, the engineer and contractor in charge of the construction, character of sub-base, causes of failure, if any, etc. This historical data has been courteously furnished to the Automobile Club of Southern California by the State Highway Commission without charge for the clerical work.

C. A general description, accompanied by numerous photographs of each section, bringing out the special points of interest that have been noted.

This extensive data that has been so collected is not included in this report as such, but it has been used in the study which has been made and is compiled in the accompanying tables. It is the basis for the general statements contained herein.

In making these investigations the agreement was reached between the Automobile Club of Southern California and the State Automobile Association that the inspection of highways of the State will be divided between the two clubs on the southern line of Fresno County in the San Joaquin Valley and the southern line of Monterey County on the coast. While the inspections of these respective districts are thus assigned it was agreed that there should be an interchange of data between the engineers of the two clubs and mutual co-operation along the lines of consultation.

While the only road system described in detail in this report is the State highway, many miles of county roads have also been visited. Because of the numerous independent authorities in charge of the county roads, they furnish a greater variety of types for study.

As a result of the field inspection, the State highways have been segregated into three classes called "good," "fair" and "poor" roads in order to assist in arriving at general conclusions as to their condition, and so as to be able to express in terms that are readily understood, their **present status**. In order to make such classification, it is necessary to have ideas as clear cut as possible of what is intended; and particularly when these inspections are made by different persons, the classifications of the roads must be standardized; therefore, the following definitions have been adopted:

DEFINITIONS OF CONCRETE PAVEMENT

Classed as They Now Exist

1. A **Good** pavement may have:

   A. Transverse cracks every 15 to 30 feet, but without raveling.

   B. Longitudinal side or diagonal cracks which show no raveling or movement of the slab at intervals of not less than 300 feet.

   C. The sides of the concrete slab should be firmly resting on the sub-base.

   D. The surface should be smooth so that machines without shock absorbers may run smoothly over its surface at all speeds up to 35 miles per hour.

   E. Fine surface cracks or a few small irregular cracks are permissible for this classification if the concrete is otherwise good. Small triangular patches at the edges of the slab at the transverse cracks are permissible if not occurring at intervals of less than 200 feet.

Longitudinal crack over adobe soil south of Arroyo Grande, San Luis Obispo County. Age of pavement 1.65 years.

Good road south of Los Alamos, Santa Barbara County.

13-5 Intensive longitudinal cracking and displacement of pavement, Santa Barbara County. Caused by lack of drainage and changing in volume of sub-base due to wetting and drying. Pavement in this condition is classed as poor. It is ruptured and displaced in the zone of travel and disintegration will follow fast.

12-7 Intensive random checking and longitudinal cracking 3.9 miles north of El Capitan, Santa Barbara County. Pavement in this condition is classed as poor. Disintegration will be rapid with pavements in this condition.

2. A **Fair** pavement may have:
   A. Transverse cracks at intervals of 15 to 30 feet, also occasional diagonal side or longitudinal cracks which do not show bad raveling or movement, at intervals of not less than 100 feet.
   B. The edges of the concrete slab may show some raveling but the concrete should be firm.
   C. Slight corrugations on the surface are permissible, but passenger cars should travel over its surface without violent impact at speeds up to 35 miles an hour.
   D. The concrete slab should rest on its sub-base over its entire length.

3. A **Poor** pavement:
   A. In addition to the transverse cracks which are unavoidable there are in this instance diagonal and side cracks occurring at intervals of every 100 feet or less, showing raveling and movement of broken blocks, or
   B. The sides of the concrete slab are broken in large triangular or irregular blocks with raveling edges, or
   C. The concrete is not resting on its sub-base, especially at sides, whether broken or not, or
   D. The concrete itself is disintegrating or badly checked. Such a pavement shows patches at intervals of 500 feet or less; depressions in the surface due to broken up concrete. Such a road requires reconstruction at an early date.

The above classification applies to the **present condition of the pavements without reference to age or service.** Frequently pavements that have been badly broken have been surfaced with asphaltic compounds, covering the cracks so that they appear in better condition than they really are. For this reason the inspection probably shows too little bad pavement.

MACADAM AND ASPHALTIC CONCRETE ROADS

A good macadam or asphaltic road is smooth and sound and at least 20 feet in width. It is without ruts, transverse corrugations, holes or ravelings more often than every 500 feet on the average for any such defects. A car should travel over its surface at speeds up to 35 miles an hour without vibrations or discomfort to its passengers. Small patches do not indicate inferiority. The road should be well drained and without excessive crown.

A fair macadam or asphaltic concrete pavement has some undulations, holes and ruts at average intervals of not over 250 feet. It shows some material neglect in upkeep. The side may be somewhat raveled, but the effective width of the pavement must not be less than 18 feet. A car traveling at speeds not to exceed 35 miles per hour should move over its surface without violent vibrations. There is good drainage.

A poor macadam or asphaltic concrete pavement: Such a road contains holes, ruts or transverse corrugations at intervals averaging less than 200 feet so as to prevent riding in an automobile with comfort over its surface at over 20 miles per hour. Poor drainage may cause it to be in this condition and therefore placed in this class. The road shows neglect, poor foundations and marked deterioration.

Where any of the above described roads, whether concrete or otherwise, have been repaved, such mileage is noted in the tabulation of poor road, and the new pavement replacement also should be separately tabulated in addition, according to its present condition.

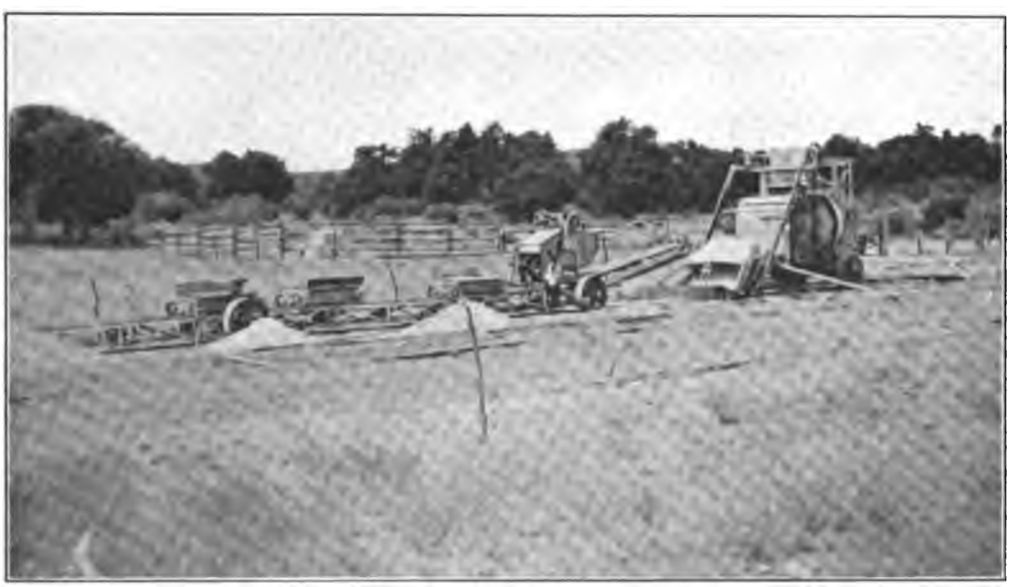
After a detailed examination of the pavements and soils for each section of the road and their classifications according to the above definitions, the conclusions of the inspectors have been reviewed by the consulting engineers and the classifications confirmed in a general way. In these field reviews Engineers of the Highway Commission, some of the cement manufacturers, as well as the makers of special types of pavement, have courteously accompanied your engineers and aided in the work with their technical data.

22-1 View of Riverside Road from Mt. Rubidoux, Riverside County.

21-2 View of good concrete pavement on Valley Boulevard near Puente, Los Angeles County.

22-5 View of good oil macadam road on Claremont to Pomona Boulevard, Los Angeles County.

5-6 Mechanical charging and measuring device on paving job near Jacumba in operation, San Diego County.

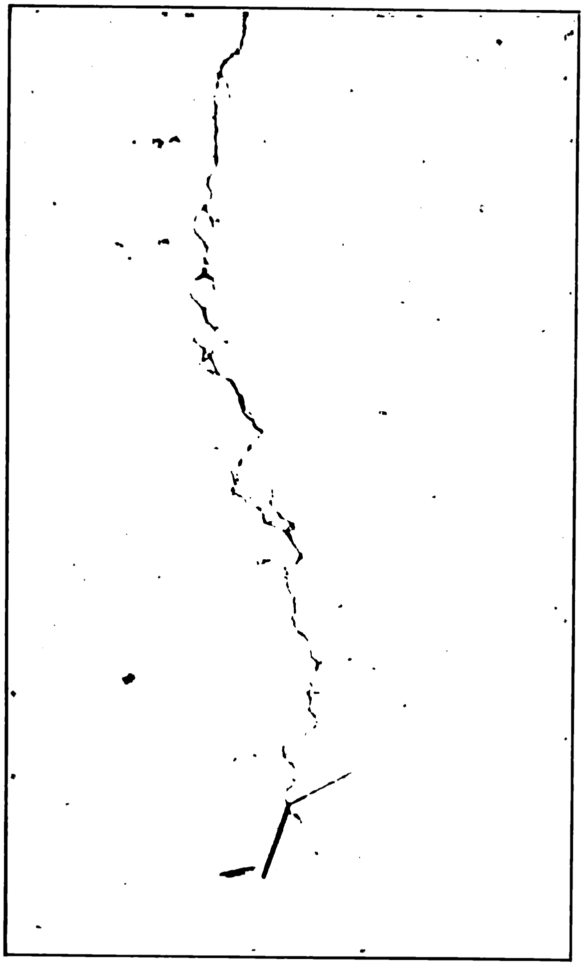


Mechanical charging and measuring device used on paving job near Jacumba, San Diego County.

It would be tedious and monotonous to give a detailed description of the inspection of all these Southern California roads. The essence of the investigation is contained in the summary of results in Table No. 20, page 101. Numerous photographs, however, were taken of this work and these are made a portion of the report. The minute defects of the concrete cannot be shown in pictures, but the general condition of the pavements where the failures are extensive may easily be seen. There are many miles of good pavement that have not been photographed because it would lead to extensive repetition. The reader is referred to the photographs throughout the report as illustrating the present condition of the roads in widely separated portions of this section.

The inspectors' reports show that one of the most persistent and serious causes of failure is longitudinal cracking, which usually occurs at one-third points in the width of the pavement directly in the zone of travel. There are also frequent triangular breaks in the slab which coincide with the transverse shrinkage cracks. Surface abrasions due to traffic are reported to be immaterial. Random checking, such as is found in the Ridge Route and on the highway between Santa Barbara and Gaviota, is particularly serious as the only remedy consists in resurfacing the pavement at large expense with new material, such as is being done in the Conejo region and on the south side of the San Fernando Valley, or entirely rebuilding it. These random check cracks are of uncertain and various causes, probably the dominating one being the use of dirty sand or the rapid drying of the green concrete after it is first cast. There are also instances of failure due to poor concrete possibly caused by insufficient water being used in its curing. A case of this kind was found near the western foot of the Conejo Grade. The report of the Committee on Width and Thickness of Slab and Reinforcement, attached hereto, enters into detailed discussion of these various classes of failures and the remedies that may be applied for their correction. In the comparison of California pavements with those of other states, the importance of smoothness of surface is emphasized. (See page 32.)

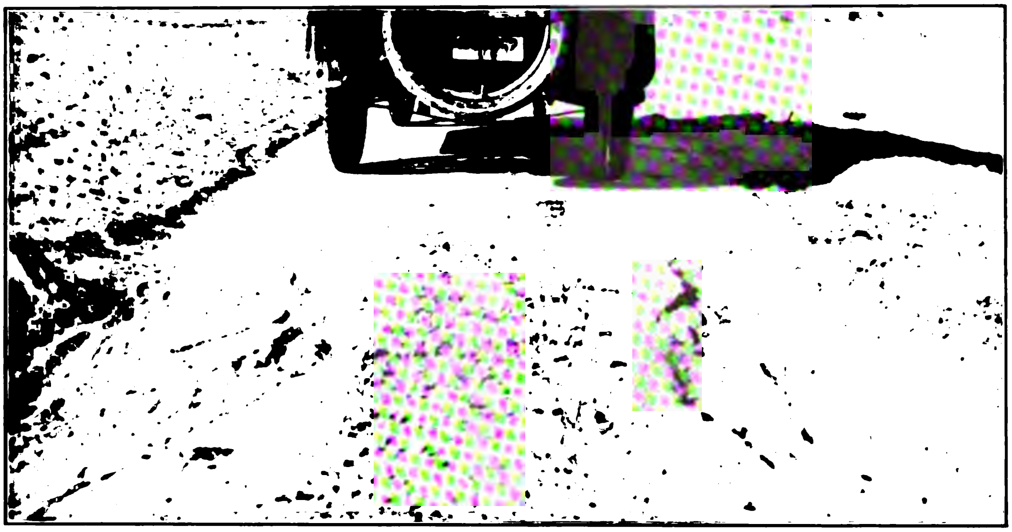
In the construction of the Mint Canyon Road, the broken stone for the pavement was obtained near the mouth of the Canyon and hauled over the pavement soon after it was built, to the front near the top of the hill, in 5-ton trucks. These trucks returning empty ran at speeds as high as 35 miles an hour down hill. The sides of the pavement so used, at the end of the job required substantial repairs. In a similar way, extensive hauling was done by the contractors in the construction of the pavement on the Conejo Grade, heavy loads of rock and sand being hauled to the front over the pavement as built, resulting in serious damage thereto. It is remarkable that those who were in charge should admit of such abuse of their own work. After the attention of the Highway Commission was called to this matter by the Automobile Club filing with it protests on their own part and in behalf of residents in the neighborhood of Conejo, this injurious use of the road was finally stopped.



Cracking and raveling in reinforced concrete, Ventura County.

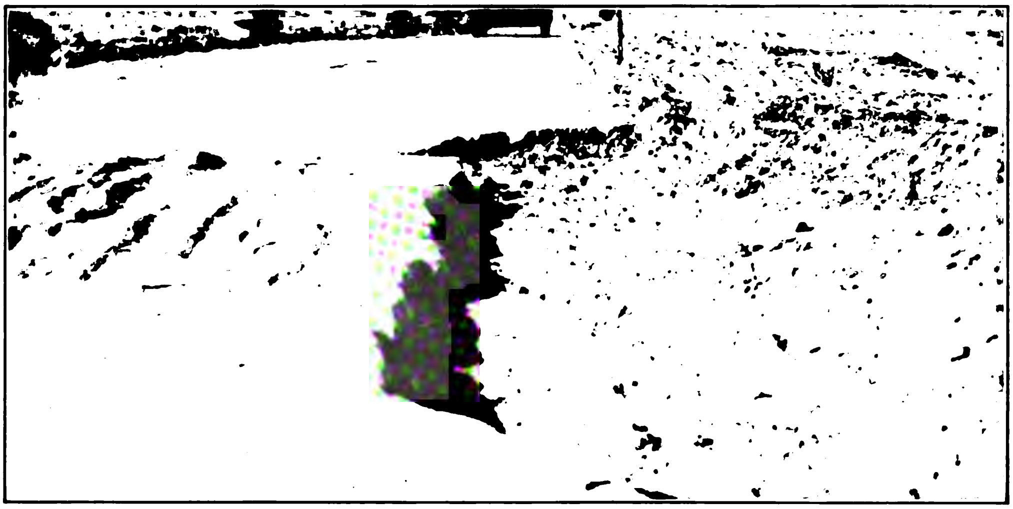
Conejo Grade, breaking up of concrete and random cracking, Ventura County.

Cracking and raveling in plain concrete, Gaviota, Santa Barbara County.



Showing 8-foot pavement between Triumfo Waste and Kane Springs damaged by storm water, Imperial County.

Repairing concrete base near Gilroy, Santa Clara County.



Showing storm damage to 8-foot pavement south of Kane Springs, Imperial County.

LOCATION OF ROUTES

The location of the California State Highway is largely specified by law. As built it has followed these instructions in Southern California, to-wit: A main line down the coast to San Diego and another trunk line down the San Joaquin Valley to Los Angeles. Connections of the county seats by the most practical routes is also specified. This latter has been partly accomplished by the acceptance of county highways as a portion of the State highway system.

A consideration of the routes in Southern California that have been adopted would be incomplete without referring to the Imperial Valley system. A main road was projected from San Diego to El Centro under the first bond issue.

In the First Biennial Report of the California Highway Commission, page 25, it is stated as follows: "The Second State Highways Act of 1915 sets aside the sum of three million dollars for the construction of the following projects, all to be by the most direct and practical route,"—one of which is "an extension of the San Bernardino County State Highway lateral to the Arizona state line near the town of Yuma, Arizona, via the cities of Brawley and El Centro in Imperial County."

This three million dollar fund was for roads to be built jointly by the State and Counties. Imperial County developed some water along this route by sinking wells and built a bridge across the San Felipe Wash near the southwest corner of the Salton Sea. The portions of this route remaining to be constructed are those lying within the irrigated district of Imperial Valley, namely from the Trifolium Waste, northwest of Brawley, to the High Line Canal, southeast of Holtville; also all of that portion lying between Yuma and the High Line Canal excepting 6.55 miles over the sand hills and one mile of Willite, ten miles east of Holtville; also all of that portion from the Trifolium Waste northwest of Brawley, to the north line of Imperial County. However, beginning at the Trifolium Waste and running north a distance of 18 miles on the west side of the Salton Sea, the State has completed 12 miles of 8′ concrete pavement and some 6 miles of 15′ pavement. A contract is now under way at the north line of Imperial County upon which approximately one mile of pavement has been completed to date. From the north line of Imperial County to Redlands there is, at the present time, one contract under way adjacent to the county line upon which approximately one mile of pavement has been completed. Three miles of pavement have been completed just south of Coachella and a grading contract between Redlands and Banning has just been finished. Between Beaumont and Banning approximately three miles of 16′ concrete pavement was built by Riverside County. This will be taken over by the State as a part of the State Highway System.

About 55 miles of State highway has been completed on the route from San Diego to El Centro. The remaining 60 miles have either been graded or are under contract for grading by the State.

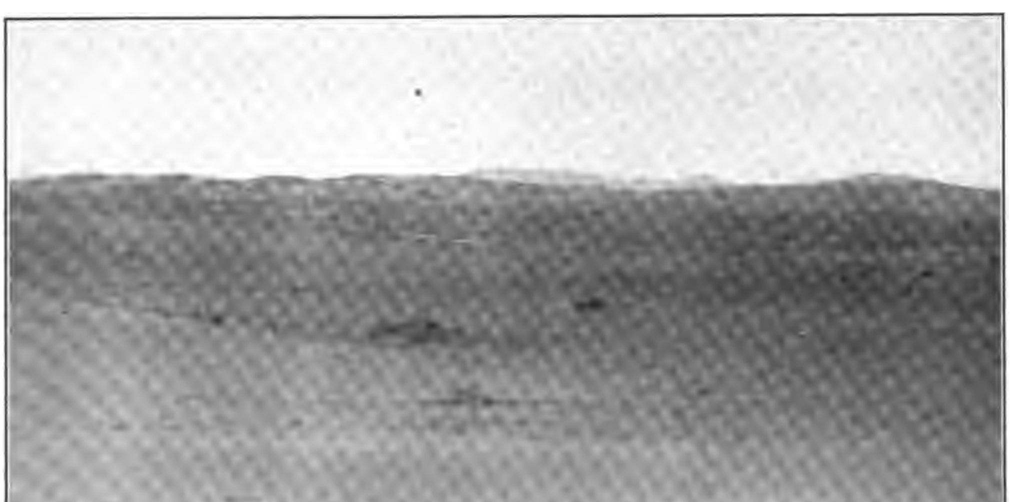
The general route as outlined by the law projects a road through the sand hills by way of Holtville and Knob Station to Yuma. A road has been constructed 8′ wide of 4-inch plank over the "Sand Hills." This is practically impassable due to drifting sand for a greater portion of the year. Warning signs have been placed at both ends of it informing the public that a trip over it is hazardous. Our inspectors went over this road and not only experienced great delay in so doing but met marooned cars.

This Sand Hill road is not a feasible one to maintain. A general routing of through travel to Arizona points from the coast through these Sand Hills is ill advised.

The line from El Centro to Coachella on the west side of the Salton Sea passes through an unoccupied country where long hauls from the railroad are necessary for construction materials and where the water supply is scarce. The paving work completed has cost about $19,000.00 per mile, 12 miles of which is 8′ wide. If the line had followed the Southern Pacific Railroad much of these construction difficulties and costs would have been reduced. Water, however, on the northeasterly side of the Salton Sea is very scarce. Drainage problems are much similar.

A-15 West end of plank road through sand hills, Imperial County.

A-16 Example of wind abrasion on plank road, Imperial County.



A-17 General view in sand hills, Imperial County.

The Imperial Canal System extends to Niland and the country in this region is undergoing development. From Niland a road to El Centro would run through a highly improved region. The road to Arizona should be located generally along the Southern Pacific main line to Yuma both on account of the freight facilities that are offered for construction materials and the more direct communication with Arizona points from the centers of population of Southern California but more particularly because of the avoidance thereby of the drifting sand dunes, through which no road can be properly maintained. The people of the larger towns of Imperial Valley could reach Los Angeles points as readily by a line lying on the easterly side of the sea as one on the west, the distance being about the same. The Imperial Valley has its commercial connection either with San Diego or Los Angeles rather than to the east. The Arizona road system, which is being built to Yuma, would be best accommodated by a route along the Southern Pacific Railroad.

The attempt to maintain a road through the Sand Hills probably must ultimately be abandoned and the route suggested above constructed if permanent connections are to be established between California and Arizona points.

A careful study of the law and estimates should be made to determine whether the portions of this route which have been constructed on the west side of the Salton Sea and through the Sand Hills had better be abandoned and the route built along the Southern Pacific lines as suggested above, connections being made from Niland to Brawley and El Centro.

WASHINGTON NOTES RELATIVE TO PAVEMENTS

All new primary roads in the State of Washington are 20 feet wide, and the secondary roads are 16 feet. The 16-foot roads that have been built recently are 6 inches thick on the sides and 7½ inches in the center. The original road from Olympia to Camp Lewis, built in 1914, was 16 feet wide, made of a 1-2-4 mix, 5 inches thick on the sides and 7 inches in the center. It was found insufficient to accommodate the traffic and in 1918 a second parallel slab 16 feet wide, 5½ inches thick at the side and 7 inches in the center was laid.

Between Seattle and Everett there is an existing paved road 16 feet wide. A new road paralleling the original road within a few hundred feet is now being built with better alignment and grade. It is proposed to put a concrete pavement on this new grade 28 feet wide, 8 inches thick on the side and 10 inches thick in the center.

There is a law in the State of Washington that provides for co-operation between the State, the Counties and adjacent land owners for the construction of secondary roads. These local property owners pay 25% of its cost. Originally these roads were built 16 feet wide. The property owners now are insisting on an 18-foot minimum width. There are said to be no requests coming in to the authorities for narrower pavements; the insistence is that the roads should be of permanent construction. These three examples relative to width of pavements in Washington illustrate the growing demand on the part of the public elsewhere for wider and better roads. It is believed the same sentiment exists in California.

Mr. R. H. Thomson, former city engineer of Seattle and at present a prominent consulting engineer on road work in the Northwest, states that it is necessary to look into the future and prepare for still heavier traffic than we have been having in the past. He takes the position that the development of this freight traffic is of great importance. He believes that we should contemplate loads of 40 tons on six wheels and he proposes a slab 20 feet wide, 7 inches thick on the sides and 8 inches thick in the center. He states that for congested traffic, especially of large trucks with trailers traveling at night, a width of at least 20 feet is necessary.

The aggregates for concrete in Western Washington usually are obtained within a short distance of the work, pits often being opened alongside the road. The cost of these pavements in 1920 ranges from $2.07 to $2.90 per square yard, including the preparation of the sub-base.

10-4 Long longitudinal crack on clay fill north of Ventura, Ventura County.

10-10 Typical failure in county-built asphalt pavement near Carpinteria, Santa Barbara County.

F Columbia Highway above Portland showing gutters to remove water from side hill.

B Sign at city limits of Olympia at point where black top pavements begin, to warn motorists against danger of skidding.

The average for the State for this year is said to be $2.38 per square yard for pavement alone. The average is about 5.1 square yards per cubic yard of concrete. The average cost of this concrete per cubic yard in 1919 was $12.50 and in 1920, $13.60. The cement cost $2.25 net f. o. b. at the factory or about $3.00 per barrel at the mixer, the mix being 1-2-3. Bids obtained for pavements of different thickness of slab in Washington are given under the discussion of construction costs on page 53. The average pavement bid per mile in Washington in 1919, including subgrading culverts, etc., which averaged from $4,000.00 to $8,000.00 per mile were: for 16 foot widths $25,000.00; and for 20 foot widths $31,000.00. The average thickness was 7 inches.

The elastite filler in the transverse joints in Washington has been changed lately (1920) from ¼-inch to ⅜-inch for summer work and to ½-inch in thickness for winter work. The increase from ¼-inch to ⅜-inch elastite adds about $400.00 per mile to the cost of the work. This form of joint is now uniformly used for concrete pavements in Washington and Oregon.

There are numerous instances of concrete roads in the City of Seattle that have been under heavy traffic for many years without any form of asphaltic topping. Spokane Street, Seattle, is 34 feet wide, made of 8-inch concrete. It has a longitudinal construction joint through the middle with staggered transverse joints every 30 feet. All these joints have quarter-inch elastite filler. The pavement has a 2-inch crown. It has had very heavy traffic and is in good condition. The sub-base is sand and silt. A great deal of brick has been laid around Seattle on top of a concrete sub-base but the practice is no longer popular. It has been found that it is not satisfactory to lay the brick with push joints directly on green concrete as the unequal expansion causes rupture. It is better practice to put a sand cushion between the two materials. The prevalance of rains and fogs resulting in wet pavements make the concrete roads preferable to the asphaltic topped roads on account of the danger of skidding on wet pavements. There follows a table giving the details of road maintenance in the State of Washington.

In conclusion, the roads in western Washington are of much heavier construction, of richer mixture and more carefully built than those to which we are accustomed in California. They are usually in good condition. This is largely due to the excellent natural foundations on which they are built. Even with the fine practice there found, when the pavements are built on new clay subgrades they have some longitudinal fractures where examined.

The State of Washington is constructing its highways from current revenues by direct appropriation. A large state highway bond issue has lately been defeated.

STATE OF WASHINGTON

MAINTENANCE, REPAIRS, EQUIPMENT PRIMARY STATE HIGHWAYS

TYPE OF SURFACE	1917 (7 Months, June-December)			1918			
	Mileage	Expenditure	Cost Per Mile	Mileage	Expenditure	Cost Per Mile	Mile-Year Cost
Brick Pavement*	8.81	*$9,456.51	*$1,073.38	8.81	*$6,652.29	*$755.08	*$914.23
Concrete Pavement	90.59	5,110.60	56.41	102.38	11,427.54	111.61	106.12
Asphaltic Concrete (1)	19.74	322.21	16.32	23.24	7,871.09	338.68	224.21
Bitulithic and Warrenite (2)	14.41	3,040.50	211.00	17.77	5,143.54	289.45	316.07
Sheet Asphalt (2)	5.97	326.05	54.61	5.97	207.07	34.68	56.39
½ Width Concrete, ½ Gravel and Macadam	7.80	1,798.50	230.58	8.53	2,461.81	288.61	327.91
Bituminous Macadam	42.21	5,895.67	139.67	40.96	20,071.85	490.03	397.70
Water-bound Macadam	122.85	20,297.41	165.22	125.05	52,335.59	418.52	368.67
Crushed Rock Surfacing	54.03	8,396.81	155.41	66.30	32,063.53	483.61	403.59
Gravel Surfacing	756.33	138,199.34	182.72	825.81	353,845.15	428.48	386.02
Natural Earth Grade	121.28	10,511.82	86.67	182.13	30,185.56	165.73	159.42
Bridges, Trestles, etc.=	1.55	7,474.47	....	3.58	37,503.46	....	....
All Types	1,245.57	$210,829.89	$169.26	1,410.53	$559,768.48	$396.85	$357.54

General Notes: The cost figures include all expenditures reported upon the highway, its road-bed, drainage facilities, surfacing or pavement; also apportionment of costs of equip-

ment, supplies and supervision; covering all maintenance and repair charges during the periods indicated. Much incidental improvement expense is included. On gravel and macadam types resurfacing is charged as maintenance.

The 1917-18 "Mile-Year Cost" is the average of 1917 (7 months) and 1918 (12 months), obtained by dividing total by 1.5833.

Special Notes: *Excessive brick costs due to extensive replacements made necessary by road-bed settlement, etc. =Costs listed to "Bridges, Trestles," etc., cover special extensive repairs, replanking, etc., of structural sections of highways.

(1) ½ on concrete base.

(2) On concrete base.

OREGON NOTES

Oregon has an interesting way of caring for the construction costs on their new State road building program. The interest on the bonds is paid from the motor car license tax plus a 1c tax on all gasoline and a ½c tax on all distillate used by motor vehicles. It is said that this revenue will provide for the fixed charges on forty million dollars' worth of highway bonds. They bear five per cent interest and are issued by the State. The counties grade the road-bed and build the bridges, except where they have already reached the limit of their bond issue when the State lends them aid. The State is to maintain the roads. This law was adopted by a referendum vote. The State does not pave the roads through towns of over twenty-five hundred inhabitants.

Some interesting experimental types of road were built by Multnomah County on the Columbia Highway west of Portland in 1915. The soil is a clay loam. Many large manufacturing institutions are located along the river and the traffic over this road is very heavy.

One section was built 18 feet wide with a concrete base of 1-2-4, 5 inches thick. There is a 1-inch crown in the subgrade. The length of this section is two thousand feet. On this concrete base was placed a layer of wood blocks 3 inches thick. The surface of this pavement failed in two years. It was then replaced with an asphaltic concrete in two layers aggregating a thickness of 3 inches. The weights of trucks going over this pavement run from ten to twelve tons on four wheels. There are two-foot shoulders of oiled macadam on each side.

Another section was laid of concrete 18 feet wide and 6 inches thick. This section partly failed in two years. It is a thousand feet long. Five hundred feet of it were made of a 1-2-3½ mix and five hundred feet of 1-1½-3 mix. No material difference could be observed in the wearing of these two sections. After failure this concrete slab was resurfaced with an asphaltic concrete top 2 inches thick, using 68 pounds of asphalt to 1,000 pounds of gravel. When visited in October, 1920, the new surface was but 30 days old and in good condition.

Another section a thousand feet long was built as follows: A concrete base of 1-3-6 mix, 18 feet wide and 6 inches thick, was laid. Over this was placed 2 inches of an asphaltic top. The road now shows ridges and holes and it is starting to fail, apparently the concrete breaking down under the cover. The asphalt has also been pushed slowly down over the sides of the road.

Another section was built, a thousand feet in length, in which there is a concrete base of 1-3-6 mix. This pavement has a 6-inch curb. On top of the concrete is placed a standard brick top 4 inches thick. About 25% of this pavement, at the two ends of the section, has failed and has been resurfaced with asphaltic concrete. There is a one-inch sand cushion between the brick and the concrete. The remaining portion of the pavement is in fair condition.

This shows the failure of four different types of pavements, all of high order of construction but placed on loam or clay loam soils with very heavy traffic and poor drainage. It illustrates that all these well built pavements were unable to exist under heavy traffic on poor foundations.

E Columbia Highway, a short distance below Portland, showing manner in which asphaltic concrete is squeezed off the sub-base by heavy traffic.

D Columbia Highway below Portland under construction with asphaltic concrete.

On the Columbia Highway, 22 miles below Portland, they are building pavements of 3 inches of broken stone rolled into a medium clay loam for a width of 16 feet. On this rolled macadam base is placed 3 inches of asphaltic concrete, 45 pounds of asphalt being used to a thousand pounds of gravel. There is then placed an additional 2-inch wearing surface with 75 pounds of asphalt for one thousand pounds of gravel. The practice is to use 5 pounds of asphalt less per thousand pounds of aggregates on grades. It is said that the asphalt will move down hill, forming transverse ridges, where the grades are over 5%. The road was built in 1920 at a cost of $2.61 per square yard without subgrade. The traffic here is medium.

Under the report of the Committee on Sub-base is given a further description of these Washington and Oregon pavements as related to their sub-base conditions. It is found that where the foundations are good and well drained either naturally or artificially that the pavements last well, but where they are built on new clay soils, especially where not well drained, all types of pavements fail. Where old macadam roads on clay soils have subsequently been surfaced with either asphaltic or concrete slabs the results are satisfactory. This points to a solution of our troubles with pavements placed on adobe. Such soils should first be prepared by rolling a layer of stone or gravel into the clay and preferably letting this be done by the traffic through one or more years' time.

Because of the great importance of this subject and the many factors that are still unknown, much further study should be given to it. It is not here presumed that all desired information is yet obtained.

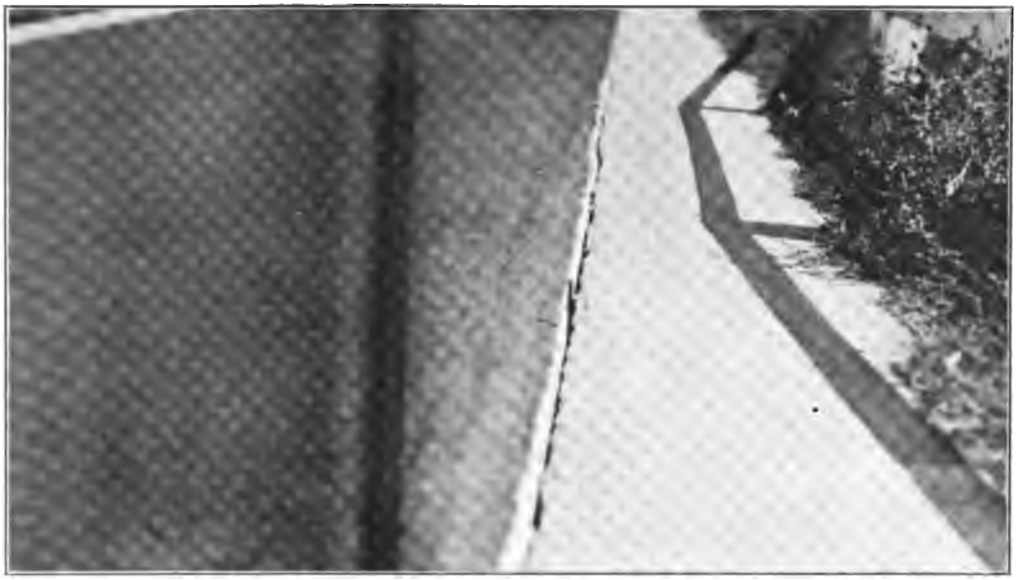
There is co-operative work in road building between the Federal government and the State of Oregon. After much discussion of the relative merits of black base (asphaltic) and hydraulic cement pavements, the following alternate sections were adopted by the State and Federal authorities and alternate bids called for thereon. The asphaltic pavement is 16 feet wide with two-foot shoulders on each side 6 inches thick made of crushed rock. Rolled earthen shoulders extend for two feet outside of the rock shoulders. Four inches of graded macadam is rolled into the sub-base where on a new grade. On top of this rolled macadam there is placed a 3-inch asphaltic concrete base with a 2-inch wearing surface superimposed. The alternate hydraulic concrete section is a slab 16 feet wide, with shoulders as before, 6½ inches thick on the sides and 7½ inches in the center, reinforced with ½-inch bars around four sides of the slab and five ⅜-inch transverse tie bars between construction joints which are 30 feet apart. Bids were called on September 28, 1920, for about six miles of these two types of pavement on what is called the Oswego branch. The award was made for an hydraulic cement concrete pavement for $3.03 per square yard, to which must be added the cost of the steel.

The lesson to be learned from Oregon is that where broken stone has been rolled into the subgrade by traffic, as in the case of macadam roads, and a pavement placed thereon, it does not break down under service within short periods even when the subgrade is clay. Drainage, however, must be well cared for.

RELATIVE LIFE OF ROAD AND BOND

Table No. 19, page 79, shows the percentages of poor roads classified as to the years in which they have been built. Giving weights to mileage and carrying out the proportions shown for the various years, we have an average indicated life of state pavements for Southern California of 14.69 years. This age of road fairly corresponds to the estimated life of concrete slabs in Eastern States.

H. E. Bigler, Road Engineer for the Illinois State Highway Commission, assumes the life of a concrete road at fifteen years. About the same estimates have been made for the Maryland roads. These California pavements were built from the First and Second bond issues. Thirty



Showing crack between concrete shoulder and pavement, Orange County. It is difficult to get a bond between shoulder and pavement in this way. Water will get under slab through this joint.

Crack between repair made to concrete base with shoulder construction, Orange County. This indicates the necessity of a wider original pavement or of a flexible oil macadam shoulder built at the time pavement is laid as called for in the plans.

per cent of our pavements are in poor condition practically before the retirement of the bonds from which they are constructed has started. The logical outcome of such a policy of financing will lead either to the abandonment of the good roads program or the financial embarrassment of the State.

The State of New Jersey was the first to fully recognize by law the seriousness of a policy of building short-lived roads with long-lived bonds. Chapter 252 of their laws for 1916 is an act concerning the issuance of highways bonds. It states (Section 4, Sub-section L):

> "Bonds used for the construction of roads and streets shall mature in not exceeding the following periods: If constructed of sand and gravel, 5 years; macadam or penetration process, 10 years; bituminous concrete, 15 years; block or sheet asphalt on concrete, 20 years; concrete constructed not less than 6 inches thick, 20 years."

The most serious phase of the California Highway situation is this relation between the long-lived bond and the short-lived road. Our 4-inch pavements have demonstrated their inability to stand the traffic on our main trunk roads. It is quite probable that even with heavy slabs on the poor soils we will continue to have failures. Until it is demonstrated to the contrary, the assumption should be that the pavement, no matter how it is constructed, will be short lived. Probably the theory of the New Jersey law would be satisfactory. If the roads are long lived, they will be an asset which will be fully appreciated. The evidence at present, both in the East and West, however, is that the life of a concrete road under heavy traffic will not be over 15 years no matter how it is built. Even if it is assumed that the concrete slab after it has failed may be resurfaced with an asphaltic concrete, as is being practiced at present both in California and Maryland, the expense of this surfacing, if it is properly done, approaches the original cost of the concrete pavement and no adequate financial provision has been made for the carrying out of this policy. Even if such a top coating were put upon a broken down concrete slab, the life of the new pavement would be short as is indicated by conditions noted in the inspection of the road between Pomona and Ontario and at other places. The State of Washington is constructing the highways of that commonwealth by direct appropriation and at the elections, in the fall of 1920, declined to authorize extensive highway bond issues.

Table No. 20

SUMMARY OF ROAD AND SOIL CLASSIFICATION

Soil	1. State and County Built Concrete Roads								2. State Maintained Concrete Roads								3. Oiled Macadam Roads Maintained by State							
	Miles	%	Good		Fair		Poor		Miles	%	Good		Fair		Poor		Miles	%	Good		Fair		Poor	
			Miles	%	Miles	%	Miles	%			Miles	%	Miles	%	Miles	%			Miles	%	Miles	%	Miles	%
Sand, Silt and Gravel	37.73	6.2	26.67	70.7	4.45	11.0	6.61	17.5	37.73	6.0	26.67	70.7	4.45	11.8	6.61	17.5	5.03	6.4	3.98	79.0	1.05	21.0	.....	.....
Loam																								
State.....	431.73	72.0	248.98	57.6	87.87	20.3	94.88	22.1	457.03	73.0	270.08	59.2	89.37	19.6	97.58	21.2	66.94	81.2	42.0	62.8	18.74	28.0	6.20	9.2
County....	25.30	93.6	21.10	83.3	1.50	5.9	2.70	10.8	......	....	......	....	......	....	......	....	......	....	.....	....	.....	....	.....	.....
Clay																								
State.....	80.87	13.4	15.85	19.7	9.65	12.0	55.37	68.3	82.57	13.8	15.85	19.2	11.35	13.7	55.37	68.1	7.45	9.0	.....	....	6.15	82.7	1.30	17.3
County....	1.70	6.4	......	....	1.70	....	......	....	......	....	......	....	......	....	......	....	......	....	.....	....	.....	....	.....	.....
Adobe......	37.05	6.2	2.50	6.7	7.55	20.3	27.00	73.0	37.05	5.7	2.50	6.7	7.55	20.3	27.00	73.0	2.0	2.4	.....	....	.....	....	2.00	100.0
Rock.......	14.55	2.2	8.00	55.0	6.10	42.0	0.45	3.0	14.55	2.3	8.00	55.0	6.10	42.0	0.45	3.0	0.8	1.0	.....	....	.30	37.5	.50	62.5
State.......	601.93	....	302.00	50.2	115.62	19.3	184.31	30.5	628.93	....	323.10	51.5	118.82	19.0	187.01	29.5	82.22	....	45.98	55.8	26.24	31.8	10.00	12.4
County.....	27.00	....	21.10	78.1	3.20	11.9	2.70	10.0	82.22	....	......	....	......	....	......	....	......	....	.....	....	.....	....	.....	.....

6.55 Plank and Oiled
1.00 Willite
8.00 Dirt Road, San Diego County
50.00 Dirt Road, San Bernardino County

776.70

NOTE: For actual mileage, all classes, maintained by State, add Table 2.

GENERAL DEDUCTIONS FROM THE INSPECTIONS

Pavements

From the field inspections and the studies, particularly of Table 20, page 101, and Table 19, page 79, the following deductions are made:

The greater portion of the roads that have been built by the State are of concrete on all classes of soils. The prevailing width of the primary pavements is 15 feet with a thickness of 4 inches without reinforcing. Shoulders of oil macadam, concrete or gravel are necessary on so narrow a pavement, yet of the 636 miles of state pavements constructed in the southern portion of the State 121.9 miles have such shoulders and 513.7 miles have not. The understanding has been general that they were to be built. As the larger cities and towns are approached, the policy has been followed of widening the pavements by the addition of these shoulders, or by the casting of additional slab of concrete 2 feet in width on each side of the original pavement.

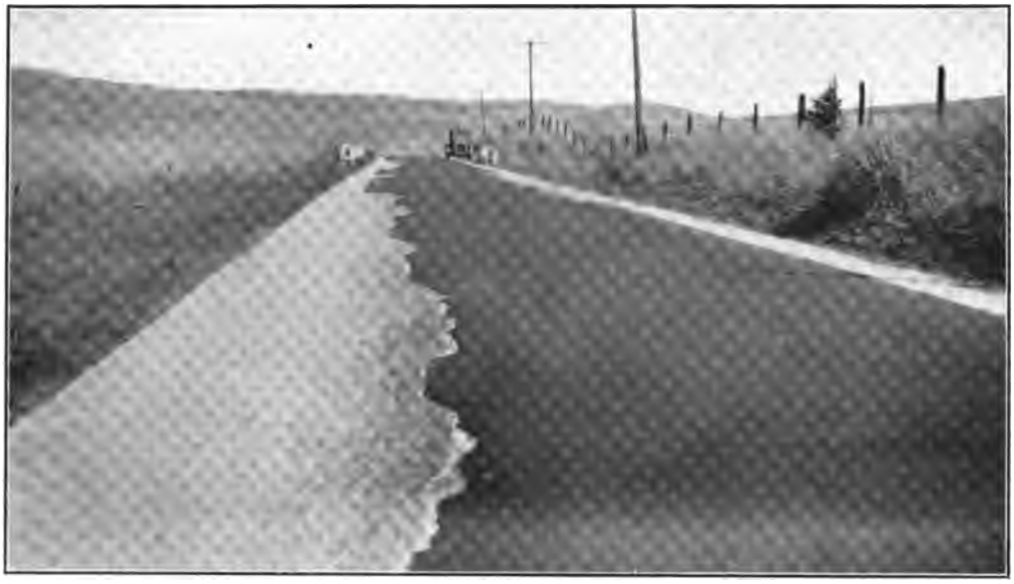
On the basis of the definitions given on pages 81-84 the foregoing inspection report shows 30.5% of the concrete pavements that have been built in Southern California by the Highway Commission are classed as poor; 19.3% as fair; and 50.2% as good. Their average age is 4.24 years. (July 1, 1920.)

On October 5, 1920, the California Highway Commission adopted a thickness of slab of 5 inches for reinforced concrete pavements. The standard width of 15 feet is to be retained but increased in certain special instances. The numerous photographs accompanying this report indicate the general condition of both the good and the poor pavements.

With an average age of 4.24 years 30.5% of the pavements in the southern portion of the State are classified as poor, and by poor it is meant that within a short period of time they will either have to be rebuilt or resurfaced. The portion classed as fair has started to break down. Comparing the present condition of the pavements with their respective ages by years, a probable ultimate life of 15 years is obtained. Mr. J. N. Mackall, chief engineer of the Maryland State Roads Commission, estimates the probable length of life of eastern concrete roads under their very heavy traffic and frost conditions at 10 years, and under moderate traffic from 15 to 20 years. (Engineering News-Record, May 6, 1920.) This relates to the pavement only. The grade or road-bed, bridges and culverts representing perhaps one-third of the total cost may be considered as permanent works. It has been shown that the state highway bonds have a life from 45 to 50 years and that their retirement does not begin until from 6 to 7 years from the date of their issue.

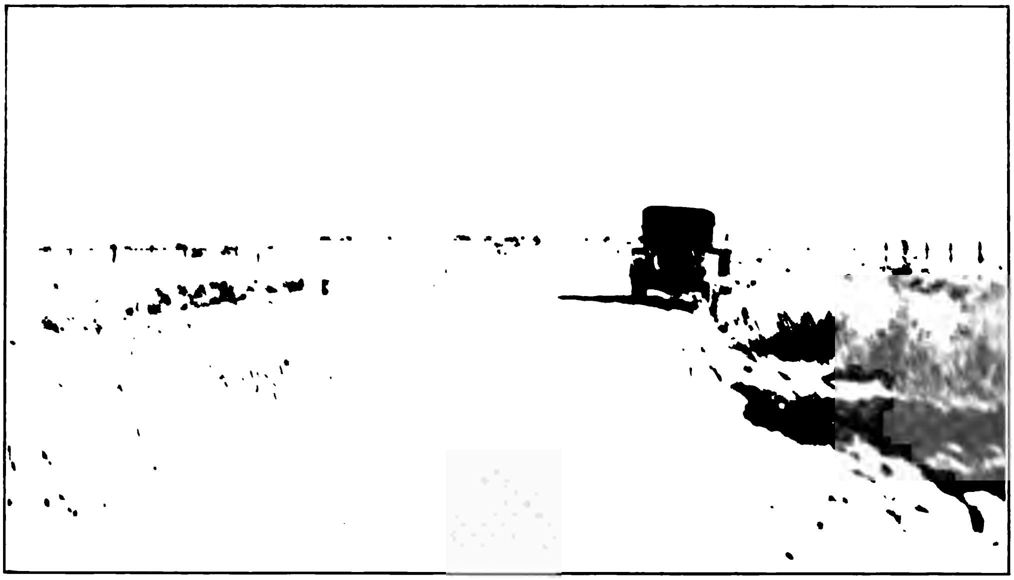
Pavements that are built with funds raised with bond issues should, if possible, be so constructed as to last as long as the life of the bond, or not fail in a more rapid ratio than the bonds are retired. Otherwise a good roads program must ultimately be greatly involved.

As has previously been stated in the discussion of the traffic census, the number of heavy trucks on our pavements has increased enormously, as shown by Diagram No. 6, page 65. The prospects are that the traffic will continue to grow, both in number and weight of the trucks, unless the loads are limited by law and the enforcement thereof. It is unsatisfactory to continue building pavements whose probable life is fifteen years, under existing conditions, with our fifty-year highway bonds. There are many miles of roads that have been built in California that have been enjoyed not only by her citizens, but by many tourists who visit our State. They have been of value not only to the owners of trucks and automobiles, but to the community at large in that they have permitted of the cheap delivery of produce and the saving of time. They have resulted in a large advance in suburban and rural values. California highways have a fine national reputation. The experience which we are passing through with our road construction is similar to that of many other states. We are facing a new and enormous transportation problem that involves the public welfare. We must continue to have good roads. They should, however, be better built for longer life on a more rational basis of financing.



Repair made to concrete base with shoulder construction, Orange County. Original pavement 5.10 years old.

Concrete shoulder construction, repair to original base and longitudinal crack, Orange County. Original pavement 5.10 years old.



Showing deformation of reinforcing bars. Reconstruction south of Bakersfield.

Showing reconstruction work south of Bakersfield. Impossible to properly place reinforcing bars in rest of pavement with this method.

The success or failure of the pavement largely depends upon the condition of the soil upon which it is built as indicated by the inspections. Probably this is as great or a greater factor in its life than the volume of traffic that passes over the road. On sand and gravel soils having good natural drainage our highways have stood up fairly well.

As the soil or sub-base on which the surface has been laid is a large factor in its life, the pavements that have been studied have been grouped in this regard as shown in Table No. 20, page 101. The soil survey maps of the Bureau of Soils of the Department of Agriculture have been used in making this classification where they are available. 117.92 miles of State roads have been built on clay and adobe soils in Southern California, of which 82.37 miles are classed as poor, or 70% thereof. Of 37.73 miles of pavement laid in the southern portion of the State on sand and gravel soil 70.7% are classified as in good condition. The macadam roads on this class of soil are reported 79% good and 21% fair, and none poor. The concrete highway in Ventura County east of Camarillo to the foot of the Conejo Creek Bridge on sandy loam is in excellent condition. East of the Conejo summit on the adobe soils it has failed and is now being rebuilt. Not only concrete roads but macadam on loam or sandy soils make good showing. The water-bound macadam road north of the Town of Lankershim in the San Fernando Valley, has stood a heavy traffic for the past ten years with slight repairs, and it is in good condition. This latter road was built by the County of Los Angeles on a sandy soil. The inspection shows that of the 431.73 miles built by the State in Southern California on loam soils, 57.6% are in good condition, 20.3% fair and 22.1% poor. These conditions relate to the pavements alone.

The greatest problem that the road engineer has to face in California is the building of a satisfactory pavement on a clay or adobe soil. These types of soils shrink in drying and expand in wetting. This change in volume of the base on which a rigid slab is laid is the cause of many surface failures. This condition somewhat resembles frost action on pavements built on clay soils in the central and eastern portions of the United States.

The foundation upon which the pavement is laid is the essence of its success. Where old macadam roads have been in operation for a term of years and the rock rolled into the sub-base, a wearing surface can be superimposed which will give good satisfaction whether it be an hydraulic cement or asphaltic concrete. The careful preparation of the sub-base improves the life of the road. The sub-base should be worked and rolled for the entire width of the road including the shoulders.

The reinforcing in a thin slab does not materially strengthen a thin concrete against fracture by tension. Its purpose is to add to the flexibility of the pavement and to hold together detached fragments when they are broken. Reinforcing is of less importance on soil having good natural drainage than on foundations that become alternately saturated and dry.

Where the heavy soils are encountered, there is no single specific remedy against breakdown. Every precaution should be taken, such as adequate preparation of the sub-base, the widening of the slab, careful attention to drainage and the use of oil macadam shoulders together with a thicker and reinforced pavement.

Failures have been mostly due to heavy traffic, to unsatisfactory sub-base conditions, and to inadequate design. They have resulted in 30.5% of the roads in the southern section of the State being classified in poor condition.

Heavy Traffic

As stated in the discussion of the traffic census, the California law provides that trucks are limited to a load of 800 pounds per inch width of any tire. This law has not been enforced. Practically no attention has been paid to it. The report of the Committee on Trucks and Truck Laws discusses the interpretation of this law and suggestions for its revision. Today trucks are being overloaded practically without restraint. For details the reader is referred to

Raveling at edge of longitudinal crack north of Goleta, Santa Barbara County.

Longitudinal cracking on adobe soil north of Goleta, Santa Barbara County.

13-8 Showing unsupported pavement over adobe subgrade. Note reinforcing steel exposed in front of hammer. 2.9 miles north of San Luis Obispo County line. San Luis Obispo County.

Broken down edge of pavement. 4.6 miles north of San Luis Obispo County line, San Luis Obispo County.

the portion of the report dealing with the traffic census. Despite these excess weights, it is believed that most of the failures in the roads have not been caused by overloading alone, but in combination with conditions of poor sub-base and speed. The Highway Commission maintains that legislation is adequate to regulate these violations but delinquency lies in their enforcement. They recommend a state motor police under the Motor Vehicle Department. The State Highway Commission has power to revoke licenses.* The Motor Vehicle Department has police powers.* On many of our valley roads it is possible to approach the City of Los Angeles without surmounting any steep grades. Roads originating in the San Fernando Valley take a water grade into the city. Roads leading from the San Bernardino and San Gabriel Valleys and from the Coastal Plain south and west of Los Angeles and from the harbor are free from hills. As the pavements are smooth, the truck owners find that the economy in their operation lies in carrying maximum loads. The limit of the loading is often based on the ability of the truck to start with the load. The drivers say if they can start they can keep going to their destination.

Particularly where sub-base conditions are poor as with an adobe or clay soil and the slab is imperfectly supported as indicated in Photograph No. 13-8, page 107, where the soil has shrunk away from the concrete at the edge of the slabs, loads of the character described above quickly develop not only longitudinal cracks, near the sides or in the center of the slabs, but also break triangular blocks of concrete at the corners where the unavoidable transverse cracks or expansion joints occur. There rapidly follows a breaking up into smaller fragments and possibly because the sub-base is made with a crown the jar resulting from the traffic sets up a slight lateral movement of the slab causing the widening of the crack. Unless it is promptly filled with some impervious material such as asphalt, the winter rains get through these cracks in the slab, soften the ground thereunder and in the case of adobe soil produce a swelling which aggravates the situation. There results a broken down pavement, the remedy of which is expensive and unsatisfactory. The reinforcing steel put in the slab prevents this enlargement of these cracks and holds the fragments together rather than preventing the original break. The report of the Committee on Sub-base describes this condition.

The growth in the number and tonnage of trucks in California during the last seven years has been in excess of conditions that could have been reasonably anticipated at the time the original design was made for the pavement for the state highways, as shown by Diagram No. 5, page 58. Statistics are not available on the increase in carrying capacity of the trucks during this period but it is obvious that the growth in this regard is equally great.

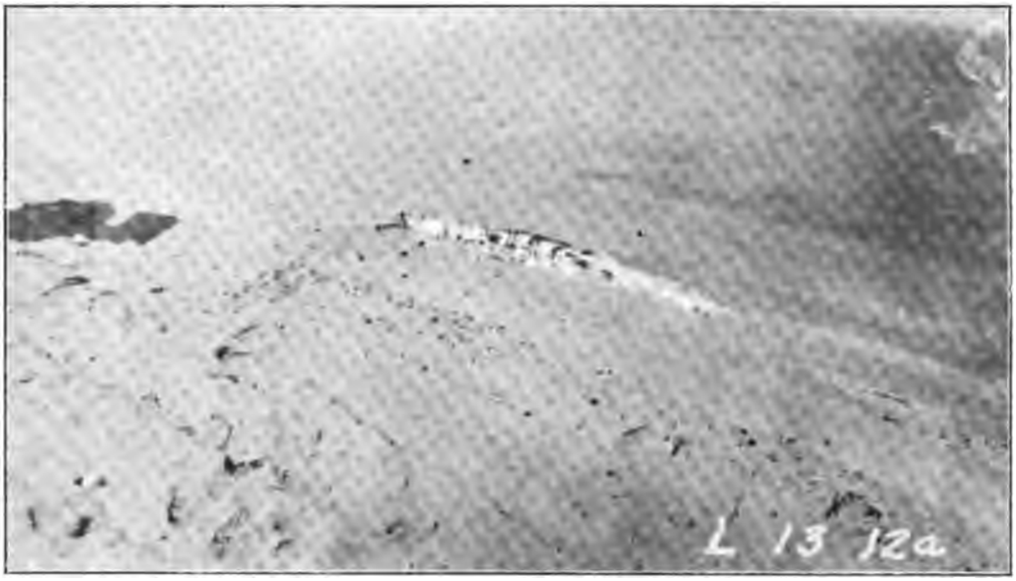
Out of the 500 trucks that were weighed on the public scales of Los Angeles in August and September, 1920, 114 were one ton; 61 were one and one-half ton; 93 were two ton; 128 were two and one-half ton; 27 were three ton; 51 were three and one-half ton; 53 were four ton and 110 were five ton. Out of 637 trucks that have been weighed in and outside the City of Los Angeles, 15% were five-ton trucks. Table No. 21 indicates that the mean and maximum gross loads of these 637 trucks were as follows:

Table No. 21

WEIGHTS OF TRUCKS IN LOS ANGELES IN 1920

Nominal Capacity	Average Gross Weight	Maximum Gross Weight
1 ton	6,420 lbs.	11,400 lbs.
1½ ton	9,243 lbs.	13,750 lbs.
2 ton	12,672 lbs.	21,500 lbs.
2½ ton	13,692 lbs.	25,175 lbs.
3 ton	16,259 lbs.	23,800 lbs.
3½ ton	18,580 lbs.	29,280 lbs.
4 ton	18,968 lbs.	26,860 lbs.
5 ton	21,054 lbs.	30,085 lbs.

* Sec. 32B, Motor Vehicle Act, 1915. Amended 1917.



Ventura County highway showing depressed oil shoulder and raveling of edge of concrete pavement.

L-8-2 Ventura Road west of Encino Ranch showing pavement broken down under traffic, Los Angeles County.

It is impossible to make any design for bridges or pavements that will carry unlimited loads. No railroad system would tolerate unlimited loads. The present law forbids it. There is no fairness in permitting a small number of truck owners, for the sake of slight additional profit to themselves, to overload the expensive structures to their destruction in disregard of the rights of the great mass of the taxpayers of the community. We should put some reasonable limit on the load such as 10,000 pounds on any one wheel and substantially improve and strengthen the roads we build in the future. It is demonstrated and admitted that the California pavements that have been built in the past, fifteen feet wide and four inches thick, are now inadequate.

Photograph No. L-8-2, page 109, shows the effect of traffic of this nature on the concrete pavement on the south side of the San Fernando Valley between Universal City and Encino. The original pavement in this section was 15 feet wide, 4 inches thick, not reinforced. The concrete is in large part broken up in blocks approximating from 6 inches to a foot square. This pavement was built in 1913. It is 6.55 miles in length. Its original cost was $12,920.00 per mile. There has been expended on it for resurfacing with asphaltic concrete, widening shoulders, reconstruction and other forms of maintenance during the last six and a half years, approximately an average of $13,000.00 per mile and there are substantial portions of this road that are now in an unsatisfactory condition. The photograph shows the repair gang at work. The concrete is picked out in these small blocks rather indefinitely and patched either with precast blocks or by new sections of slab. The maintenance gang has a discouraging task continually before them because of the extent of this breakdown. This section of road is in worse condition than the average and is referred to because more data is now (October, 1920) available in reference to it than other sections. This Ventura Highway, from Universal City through the San Fernando Valley to Ventura County, has been out of commission for nearly a year's time, largely on account of repair work, but partly on account of the laying of a new pavement on the Conejo grade. The public has thus been deprived of the benefit of its investment therein during this period. This condition of the great overloading of the highway by the larger sizes of trucks is serious and should be remedied by the enforcement of the laws or else we must contemplate a continuance of these conditions with the roads we have so far built, at least on the clay soils, which apparently will soon lead to the destruction of our present highway system.

Sub-Base

A report on Sub-base Conditions is presented on page 121 of this report.

Within practical limits of cost no pavement can be designed to stand present day traffic conditions unless it is completely supported on its sub-base. Only a painstaking attention to construction details will result in a satisfactory foundation for the slab. In California we have a great deal of a soil that is described as adobe and nearly all pavements of all classes which have been laid thereon, where traffic conditions have been severe, have broken down, as is shown in Table No. 20, page 101. Adobe is a term applied to any fine grain soil whether clay or silt. The typical structure shows shrinkage cracks at close intervals when dry. It increases in volume on being wet. Materials having adobe structure are "reversible colloids" which means that they have the property of alternately when dry absorbing moisture and becoming gelatinous in character, thereby swelling and when drying of shrinking with their varying moisture content. Photograph No. L-13-10, page 111, shows shrinkage cracks in adobe soils. Under the direct action of the sun they will contract about 10% of their volume laterally and an undetermined amount vertically. Adobe cracks are frequently found in which a yardstick can be inserted from 24 to 30 inches. A block of adobe excavated on the road between Ventura and Ojai shows cracks 2 inches wide at the ground surface, ¾ of an inch wide 14 inches below the surface and readily detected at depths of 20 inches. Samples

Shrinkage crack in adobe near Ventura.

Shrinkage crack in adobe near Ventura.

Shrinkage away from pavement near Santa Barbara.

of this adobe soil have been selected from various portions of Southern California and sent to the Civil Engineering Laboratories at Berkeley for the purpose of testing the extent to which they will expand and contract and the force with which they expand.

We, therefore, have in large districts of California, plastic soils that change their forms between wet and dry seasons upon which a rigid pavement slab is laid. No **pavement** within reasonable financial limits can be built to withstand heavy loads, if it is not fully supported. When taken in connection with the loading of the pavement, as described above, failures follow.

Photograph No. L-13-1, page 111, shows a concrete slab that was built on adobe by experienced road engineers and contractors in Santa Barbara County near the Santa Barbara Mission. A four-foot lath can readily be run under the sides of this pavement at numerous points. Photograph No. 12-6, page 106, shows the character of the results occurring when a slab is loaded under such conditions.

Search has been made by your engineers to find satisfactory pavement conditions on soils of this character both in Northern and Southern California. As a rule pavements that have been so laid five years or more where the traffic is heavy, have been broken down to such an extent that they are either in bad condition at present or they have been resurfaced at an expense as great as the original cost of the pavement by putting a wearing surface of asphaltic concrete from 1½ to 2 inches over them or in some instances by casting another slab of concrete thereon.

The California Highway Commission has demonstrated with a three-thousand-foot slab 6 inches thick and 15 feet wide reinforced and laid on the Ventura Highway west of Calabasas on adobe soil that it is possible to build a pavement under such conditions that will stand up under heavy traffic while standard types of 4-inch unreinforced slabs adjoining have completely failed. This is described in the report of the Committee on Sub-base (page 125). Between Goleta and Gaviota on the Coast Highway some reinforcing has been placed in the 4-inch concrete slab where laid on adobe soils with results that are beneficial.

It is surprising that in view of this evidence of success and failure, the Commission continued constructing this standard type of pavement 4 inches thick without reinforcing on so many miles of similar soils until quite recently in California.

In order to prevent the change in volume of the adobe soil in the sub-base it is essential to maintain a uniform moisture consistency. Apparently the adobe will shrink either laterally or vertically to a depth or width of three feet from the exposed surface. This drying out is said to be due to the existence of capillary tubes in the soil. Experiments in different classes of soils in irrigation work indicate that these dense clay soils will evaporate moisture from their surface, which is drawn from greater depth than in the case of sandy soil. It was found by tests conducted by the Los Angeles Aqueduct Bureau in Owens Valley that underground water supplies will evaporate from the ground surface when the water plane is eight feet or less from the surface. This, however, is when they are planted with native grasses. The rate of evaporation is more rapid when the water levels are nearer to the surface. It is possible that the thorough breaking up of these capillary tubes in the adobe to substantial depths will tend to diminish the changing in their moisture contents as indicated by the following:

A road that was built under the direction of Mr. Lloyd Aldrich when County Engineer of Stanislaus County in 1917, between Newman and Patterson and for a distance of several miles north of Patterson, was visited by your engineers. This pavement is concrete, 16 feet wide and 4 inches thick, slightly reinforced at the expansion joints and corners. Portions of it are covered with 1 inch of Topeka asphalt concrete. The surface of the road is maintained about 18 inches above the general ground level. The Department of Agriculture has classified this soil as "Yolo adobe" and "Yolo sandy clay." The road is now three years old and

Longitudinal cracking through cut north of Goleta, Santa Barbara County. Note absence of drain ditches. Extensive longitudinal cracking prevented through the use of steel reinforcing.

Longitudinal cracking and breaking up of pavement on fill at mouth of cut, Santa Barbara County. Pavement probably placed before fill had fully settled.

is in fine condition over all classes of soil except at its extreme north end, where it was laid through the small town of Westley, largely under the direction of the local authorities as distinct from the regular organization. The procedure as laid down by Mr. Aldrich in this work for the preparation of the sub-base was as follows:

1st. Plow the entire space across the roadway between gutters for a width of 40 feet.

2nd. Make fill with scrapers in layers of not over 6 inches.

3rd. As fills are made the material is pulverized with a spiked roller such as was used in former days with oiled roads. The fill is then sprinkled and built up in thin layers so as to moisten the adobe but not to work it into any liquid or soft condition. The moisture in this sub-base is brought to a consistency such as is contained in the underlying deeper soils.

4th. A ten to twelve-ton three-wheel roller follows the pulverizing and the entire forty feet of road-bed is thoroughly rolled in this manner to a uniform degree of hardness. As much attention is paid **to the rolling of the shoulders as to the central portion of the road.**

5th. Header boards are all set in excavation. That is, a groove is dug in which the header board is brought to a solid condition of rest. The sub-base is then scarified to a depth of 3 inches between the header boards. The loose material is then taken out from between the boards to within a depth of ¾ inch of subgrade.

6th. The subgrade is then sprinkled and rolled again or not, as required.

7th. The surface is then cut to true subgrade with a special cutting machine. No cuts in excess of ¼-inch are permitted. Any holes that are developed in this process are scarified, filled and rolled.

8th. The finished subgrade is then sprayed with water so it shows a sheet over its entire surface. This does not mean a standing pool of water, but rather a film of water. This sprinkling is repeated on the following day.

9th. The subgrade is then left for five or more days to dry.
(Mr. Aldrich states that shrinkage cracks do not develop in the subgrade during this period.)

10th. The concrete is then cast on the subgrade.

This procedure is as exacting as that required by engineers in the construction of an earthen dam. No shrinkage beneath this slab was observed. This thorough preparation of the sub-base is in contrast with other road construction jobs that were visited.

It is essential that care should be exercised in the preparation of a sub-base, otherwise no amount of detail in the preparation of the concrete slab will save the pavement.

It is surprising that with such great expenditures as have been made on highways throughout the United States so little experimental work is known of relative to the remedy for the expansion and contraction of clay foundations. Even the successful instances have not been used for the guidance of subsequent work. The efforts of the engineers of California should be untiring to find a specific remedy.

The report of the Committee on Subgrade presents numerous cases of pavements that have been laid on good and bad foundations and reference is made thereto.

The County of Los Angeles began its good road work about 1909. The traffic in this region has been very heavy and the experience of this county in the construction and maintenance of roads of various types has probably been more extended than in any other county in the State. The county authorities are now building a freight road for trucks from the city to the harbor, as follows: 8 inches of decomposed granite is rolled onto the sub-base. The slab is 24 feet wide and 8 inches thick, reinforced with No. 6 quadrangular mesh weighing 4 pounds per square foot.

In Contra Costa County a unique type of pavement is being laid composed of two separate 8-foot slabs with 4 feet of macadam pavement in the center, apparently the idea being

Typical shoulder condition on heavily traveled concrete roads. Adequate shoulder construction has been omitted. This is severe on pavement and dangerous to traffic.

Concrete shoulder construction west of Visalia. Asphaltic wearing surface left unfinished for one year.

22-4 Abuse of highway—12 tons of grapes on a 4-ton truck.

A-10 Abuse of highway—note position at edge of concrete.

20-7 Abuse of highway—note lack of tire on left wheel.

to permit of the shifting of the base of the road without the forming of the longitudinal cracks. These slabs are 4 inches thick. Sufficient experience has not been had to demonstrate the advantage of such type of pavement. The weak point of a pavement is the edge of the slab and as this type of pavement would have four of these instead of two, it appears not to be an improvement.

The consistency of the adobe beneath the concrete slab might be maintained in a more satisfactory manner if wide shoulders of some impervious material like asphaltic concrete or oil macadam were used. These shoulders being flexible and the evaporation apparently taking place within the four outer feet of the pavement, it appears that they would substantially protect the concrete slab proper. Favorable results were obtained in Monterey and Bonita Counties in this manner. However, with a slab which is but fifteen feet wide and with a heavy traffic, the tendency is for a truck to travel with one wheel on the macadam shoulder and one on the concrete pavement, the shoulder being the weaker breaks down and is apt to shear from the slab, making a rut at the point of juncture, and to a certain extent destroying the purpose for which it was placed. This is illustrated in Photograph No. L-13-12-A on the State Highway about three miles east of Ventura. Maintenance is essential to any type of pavement.

If the concrete slab was made wider, say eighteen to twenty feet, and an impervious shoulder then placed outside of it, this adverse argument would not apply so much, as there would then be less tendency for a truck to travel partially on the shoulder. It is believed that shoulders under these conditions would nevertheless be a benefit.

Width of Pavement

California pavements are dangerously narrow. The legal width of a truck load is 8½ feet or less. It is impossible for such vehicles to pass on a 15-foot pavement. The crowding of a narrow highway decreases its efficiency and is a cause of positive danger to life. On our thin pavements, the crowding of the traffic on and off the edge of the concrete slab causes it to break down. This is shown in Photograph No. 18-7. If the pavement were wider its life would be longer. California has lagged in the development of an adequate pavement to meet increasing traffic. Most of the 4-inch pavement that has been laid from the First and Second Bond Issues was composed of a 1-2½-5 mixture. The present mixture is 1-2-4.

There is no economy in the construction of light pavements when the capitalized maintenance and upkeep charges are included with the first construction cost as shown by the report of the Committee on Maintenance.

Abrasion

If a concrete mixture of adequate richness is used, such as 1 cement, 2 of sand and 3 of stone, and the quality of these materials is satisfactory and workmanship of proper standard, the resulting pavement will be such that abrasion due to surface wear will be a matter which may be neglected. Even with the California pavement as well constructed abrasion is not a serious menace within the limit of the length of the life of the slab.

Tires

Pneumatic tires are less destructive to pavements than those of solid rubber. A. T. Goldbeck, Engineer of Tests of the Bureau of Public Roads, states in "Public Roads," July, 1919, that trucks with solid rubber tires, traveling at 15 miles an hour, passing over an obstruction one-quarter of an inch high will deliver a blow on the pavement equivalent to three and a half times the static load.

The results of tests made with a Packard 3-ton truck with a 4½-ton load, having a total weight on each rear wheel of 7,000 pounds, of which 1,700 pounds were unsprung, are

Surface abrasion and random checking near Dixieland, Imperial County.

7-5 Expansion buckle and breaking up of pavement, also longitudinal cracking on clay silt soil, near Seely, Imperial County.

A-18 Typical longitudinal crack south of Nipomo, San Luis Obispo County.

A-19 Longitudinal cracking followed by breaking up of pavement near Bradley, Monterey County.

given in column 1 of the table below. The old solid tire was worn to a thickness of 1 inch. The new solid tire is 2½ inches thick, while the pneumatic tire was 42x9 inches with a 142-pound air inflation. The impacts under these cars are shown in columns marked (2) and (3).

Speed	Drop	(1) Old Solid Tire	(2) New Solid Tire	(3) Pneumatic Tire
5.7	2 inches	11,600	9,400	7,100
10.2	2 "	18,500	14,100	7,800
14.6	2 "	26,500	18,700	8,300

The exact data of the effect of pneumatic tires on the life of a truck itself could not be obtained. The Motor Transit Company operating 80 trucks on the highways radiating from Los Angeles, including some unpaved mountain roads, gives the following general information: They were having turned in for repair about one broken axle a day, the trucks at that time being equipped with solid rubber tires. They have now all been outfitted with pneumatic tires and the breaking of the axles has greatly decreased. They do not consider it economical to operate solid tired vehicles at speeds over 15 miles an hour, while the same machines equipped with pneumatic tires may be operated 25 miles per hour. It is said that a stage equipped with solid rubber tires attempting to run 25 miles an hour from Los Angeles to San Bernardino would break down. They estimate the life of a truck operating with pneumatic tires as twice that of one operating with solid rubber tires and they find it is economical from the operator's standpoint to use pneumatic tires.

Pneumatic tires do not permit of excessive overloading of trucks which, from the standpoint of the taxpayer, is desirable. It is generally recognized in laws that have been studied that trucks with pneumatic tires should be permitted to travel at higher speeds than those having solid rubber tires.

Future Policy

The future policy of the California Highway Commission should be quality rather than quantity in the construction of the road system. Undoubtedly there is severe pressure for the building of many miles of roads which are relatively unimportant. Such a program leads to reduced quality of work and design in other portions of the State where the road is essential to a heavy traffic. Public opinion in California today decidedly demands a better type of road. As the expense of rebuilding the broken down pavements develops, this will become intensified. The reader is referred to the report of the Committee on the Width and Thickness of Slab for recommendations on the design for our future pavements.

No pavement should be put down on a trunk highway in California less than 6 inches thick. On bad soil it should be 8 inches thick and reinforced. The minimum width of trunk lines should be at least 18 feet. California should be in the lead in the quality of its road work rather than at the other end of the procession.

REPORT OF COMMITTEE ON SUB-BASE

Robert Morton, Highway Engineer San Diego County, Chairman; Lawrence Moye, County Surveyor Tulare County, and J. B. Lippincott, Consulting Engineer.

December 10, 1920.

The character and preparation of the subgrade or foundation for a road are more important factors than the type of pavement to be laid thereon and the details of its construction, including thickness.

There are notable examples of oil and water bound macadam and other structurally weak pavements which have been in service for from 5 to 10 years under heavy traffic which are in excellent condition, being maintained at small cost, because they are built on well drained sandy soils. There are other examples of higher priced and stronger pavements, both of concrete, brick and asphaltic base types, which have failed because of defective foundation. Their renewal constitutes a serious engineering and financial problem. Discussion of the type of pavement to be selected for our various highway projects should not divert our minds from the more important consideration of an unyielding, immovable foundation.

In the Southwest there is a heavy clay soil, usually formed from the breaking down of shale rocks, that is locally known as "adobe." It somewhat resembles the "gumbo" in the middle west. The term applies to the structure of the material rather than to its chemical composition. It has the quality of expansion and contraction with wetting and drying. This characteristic, coupled with our California wet and dry seasons, make it an unsatisfactory foundation upon which to lay any pavement. The inspection of the improved state highways in Southern California shows that 45% of the failures have occurred on clay and adobe soils. Out of 117 miles of pavement laid on clay and adobe, 82 miles have failed, while out of 469 miles laid on sand, gravel and loam, 101 miles have failed. Other pavement failures due to foundation troubles are attributed to lack of consolidation of earth fills.

The study of the Committee on Thickness, Width and Reinforcement of Slabs demonstrates that it is beyond the limit of reasonable cost to build a concrete pavement on a sub-base that shrinks away from it, leaving it partially suspended on the sides. A non-rigid slab of macadam or asphaltic concrete forms into ruts and waves on an unstable base.

It has been too often the custom to regard a light concrete slab placed directly upon any natural soil as having sufficient strength. The same thickness should not be used under all conditions. The frequent examples of the breaking up of our concrete pavements, and the distortion of our asphaltic base types, where laid upon heavy clays, shows the fallacy of this assumption. Table No. 20, page 101, and photographs L-X and L-13-7, page 123, and L-8-2, page 109, relate to this subject.

In Washington State between Camp Lewis and Everett the concrete pavements have been laid on morainal gravels which are well drained. This is an ideal foundation. They have given good service. The width and thickness of the slab (usually 20 feet wide and 6 to 7 inches thick) is, however, more substantial than our California types. In Multnomah County, Oregon, adjacent to Portland, there is much clay. During the past excellent basaltic macadam roads have been maintained in this section. Recently many miles of both asphaltic and concrete slabs have been placed over these old macadam roads. Care has been observed with drainage. Under such conditions both types of pavements have given good service. When they have, however, built pavements on new clay grades with poor drainage trouble has developed. Macadam rolled into the clay by the traffic accompanied by good drainage is an improvement, as shown by the inspection.

Speed is usually demanded in the construction of highways. Time, weather and traffic are the best agencies to stabilize fills. The highways of Europe were not the product of a season's work. The foundations, when exposed by excavations for trenches, often showed rock

material three feet deep. The foundations of the roadways of France are the product of a gradual upbuilding process continuing for generations.

The same care should be exercised in making fills as in building an earthen dam. It should be made so dense that water will not percolate through it and so that it will settle a minimum amount. Specifications for fills are frequently prepared with care, but often they are not followed closely.

An average of $18,097.00 per mile has been paid for the construction of the roads of Southern California. Maintenance, improvements and renewals have amounted to $615.00 per mile per annum. If the life of the pavement is dependent on the foundation, it follows that on such types of soil in which danger is to be expected, substantial outlays are justified in the preparation of the subgrade. Soil surveys should be made as a part of the work of location. Much discretion should be left in the hands of the division engineer.

Time should be taken to permit earth fills to be surfaced with gravel or rock and placed under traffic for one to four years, depending on their height and the nature of the material used. Levels should be taken to determine when it has ceased settling. Frequently satisfactory materials for fills or for topping off the subgrade may be obtained in short distances.

Adobe should be discarded as much as possible in making fills and selected materials of a satisfactory nature used where possible. The discarding of adobe for subgrade is one of the surest means of solving the problem of shrinkage and expansion. On state highway work, the contractor is required to haul earth a thousand feet for the grading price per cubic yard. If the maximum distance allowed in this provision were enforced, many fills now made of adobe could be made of material taken from a good borrow, sometimes located perhaps off the right of way. Other specifications provide for the payment of 1c per cubic yard per 100 feet to haul earth one-half mile beyond the free haul. This would mean an addition to the grading price of 26c per cubic yard for overhaul. As the grading prices often range from 75c to $1.50 per cubic yard, it would appear to be possible to obtain suitable materials in many cases for the making of subgrades or low fills within reasonable additional costs.

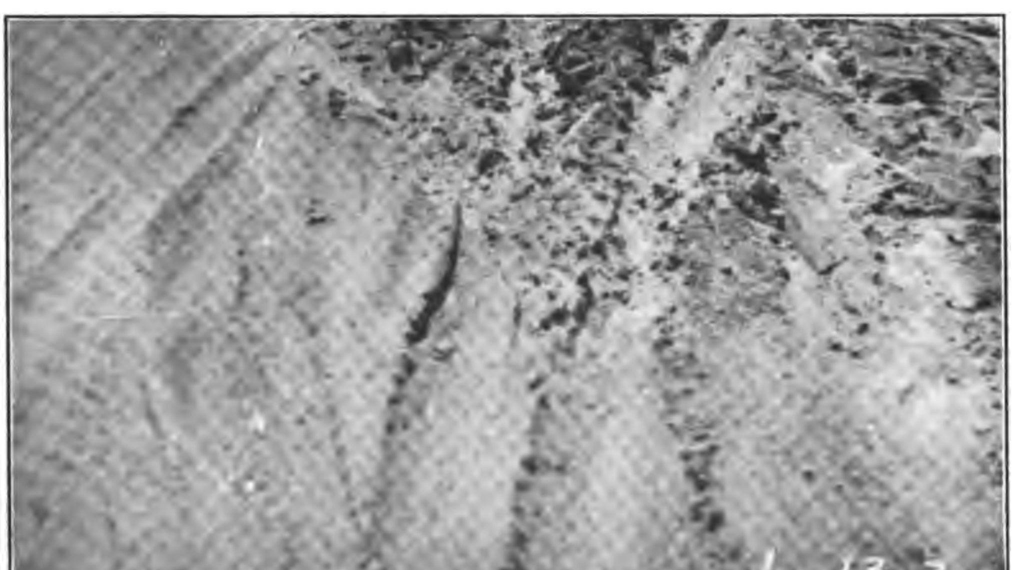
An examination of a pavement during the summer on many sections laid over heavy soil will disclose a vertical opening from ¼-inch to 1-inch in width between the soil and the edge of the pavement, except where shoulders are used. Beneath the pavement it is often possible to insert a yardstick (see photographs 8-10, page 128, and 13-8, page 107). The air has dried out the moisture and shrunken the supporting soil of the subgrade. If the pavement has not already failed, it will soon do so. When such a pavement is concrete, cracks develop usually 3 to 5 feet from the edge. Thereafter less weight is required to rupture the fragments. With an asphaltic concrete type of surface on similar soils the settlement is not so apparent. The material has elasticity, and follows the subgrade without cracking. Deformation occurs, however, and it is only a short time until it becomes so great that this type also fails.

The San Diego County Highway Commission is making a study of soils on the various routes to determine what their future action will be under various conditions of moisture. They are adopting a system of subgrade "reinforcement" or adulteration with disintegrated granite or broken stone wherever unstable conditions are encountered. No matter what subgrade treatment is adopted, steel reinforcement will be used in the pavement over the heavy soils.

It is known to sidewalk builders that a cushion of sand or cinders on adobe soil will prevent cracks. In Tulare County in 1920 bids for 1½-inch of rock and 2 inches of sand rolled into the clay subgrade were at the rate of 30c to 36.3c per sq. yd., or $2,800.00 to $3,400.00 per mile.

Photograph L-13-10, page 111, was taken on the Ventura County highway on the road between Ventura City and Ojai. In one block of this soil there was a shrinkage of one and one-half inches in twenty in one direction, and three inches in thirty-one in the other. Cracks two inches wide at the surface ran out at depths of twenty inches.

Natural asphalt pavement near Santa Barbara, Santa Barbara County.



Natural asphalt pavement near Santa Barbara, Santa Barbara County, on poor foundation.

Longitudinal cracks. Pavement on sandy soil. Caused by undercutting of water, Imperial County near Coyote Wells.

Random checking over a clay fill made from material cut from clay knob near Dixieland, Imperial County.

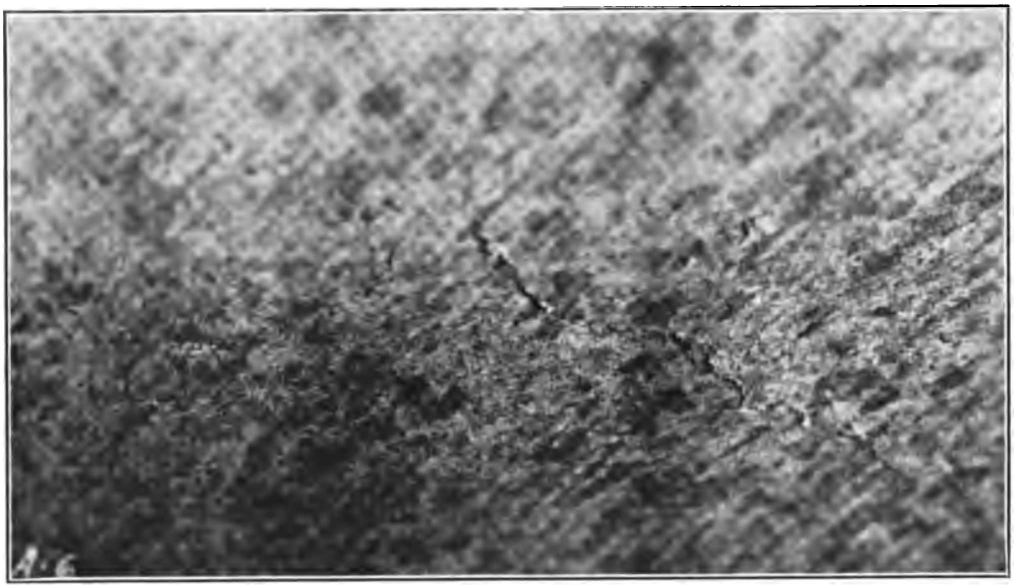
Six miles from Ventura is a concrete slab four inches thick and sixteen feet wide laid on adobe soil. It is reinforced with $\frac{3}{8}$-inch square rods transversely every eighteen inches. The mixture is of 1-2½-5. The adobe has shrunk away from the concrete on the downhill side so that a lath can be run under it for three feet in the places examined. The original crown of the pavement was two inches. A level showed that on the downhill side there now is a drop of three inches from the crown. The concrete slab has followed the adobe down to the extent of one inch without fracture. There is a fairly heavy traffic on it. No gravel was rolled in the sub-base at this point. Further on about four inches of gravel was rolled in the adobe before the concrete was laid thereon. In both instances the pavement is in good condition.

On the same road, one mile south of Tico Siding, one thousand feet of road was constructed on adobe soil. Cracks were observed to be two inches wide, and a yard stick could be run down in some of them to a depth of seventeen inches. About four inches of gravel was first placed on the subgrade and rolled into it by the traffic in wet weather. A four-inch concrete slab of 1-2½-5 mixture, not reinforced, was then placed on the subgrade. It cracked longitudinally in one year and got into bad condition. Mr. Charles Petit, the county engineer, then put a curtain wall of concrete on the sides of the pavement twelve inches deep and ten to twelve inches wide. This extended one inch above the concrete pavement. He then placed on top of the broken slab one inch of asphaltic concrete wearing surface flush with the tops of the curb. This gave a new wearing surface and stopped some of the changing of the moisture content in the subgrade. The curtain wall also held the broken slab from further movement. This resurfaced pavement has now been in service for one year and is in good condition. This road was built and the concrete originally laid during the winter or wet season. The adobe was sprinkled and rolled so that the slab was placed on the subgrade while it was quite wet. Reference has previously been made to the 3,000 feet of 6-inch reinforced concrete pavement successfully laid east of the Conejo Grade.

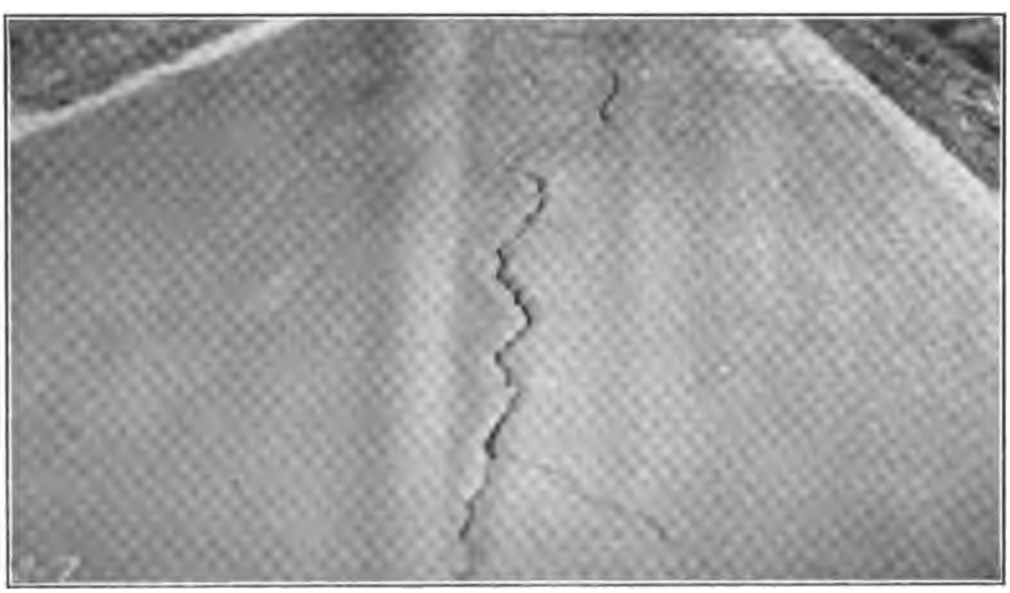
In Santa Barbara County on the "Thompson Road," built by the County, is a concrete slab four inches thick, fifteen feet wide, with a 1-2-4 mix. Good sand and stone were used. The soil on which the pavement is built is adobe. Triangular mesh was placed in the center of the slab. The adobe has shrunk away from the edges so that a yard stick can be pushed under it for its full length at all places tested. Photograph L-13-1, page 111, shows this overhang. The slab has developed cracks. At another point on the same road, under the same conditions, except that no reinforcing was used, the pavement has broken down and the fragments are moving both vertically and horizontally. In this instance the slab was also placed during the rainy season and the sub-base was rolled wet.

On the "Mesa Road," built by the same County, the pavement is of the same character except that it is five inches thick and not reinforced, the soil being adobe. It was laid during the summer, and owing to the scarcity of water, the slab was placed while the subgrade was quite dry. Little water was used in rolling. The pavement is now two years old and is in good condition, resting on its foundation. The traffic is light.

In Los Angeles County, on the road between the city and Redondo, near Strawberry Park, the soil is adobe. Cracks in the adjoining field twenty-three inches deep were measured. This locality is subject to overflow. The road is built on a low adobe fill. Four inches of decomposed granite was placed on top of the fill as a sub-base. On it the concrete slab was laid in 1915, five inches thick and twenty feet wide, with a crown of one and one-half inches. The pavement was covered with screenings and oil. It was placed on the sub-base when it was dry. The road has oiled macadam shoulders about four feet wide on each side, nine inches thick at the side of the concrete and tapered to zero at the outer edge. After the heavy rains of January, 1916, this section was overflowed **for several weeks.** The adobe grade became saturated and the sides of the slab were forced up until the pavement became concave. The soil dried out during the following summer and a large number of longitudinal cracks opened. Most of them are about four



Typical crack and abrasion, concrete pavement.



Typical longitudinal crack, concrete pavement. Laid on adobe soil.

feet in from each edge of the concrete. This is a severe situation which indicates the necessity for drainage.

It has been noted in some instances where pavements are laid in towns on adobe soils and where the sides are protected by curbs and sidewalks fewer cracks occur. For instance, on Twenty-sixth Street, in the town of San Pedro, the soil is adobe. Some cracks were measured to depths of forty inches in the soil at the side of the road. The pavement is thirty feet wide, the curbs are eighteen inches in depth. There are three and one-half inches of asphalt concrete base with one and one-half inches of asphaltic concrete wearing surface. This road leads to Fort MacArthur and during the war there is said to have been heavy war traffic over it. At present this traffic is very light. The condition of this pavement at the present time is good. It is four or five years old.

In the same town on Carolina Street, near Thirty-second Street, a cement pavement has been laid. The soil is adobe. The pavement is forty feet wide with curbs as before. There are no sidewalks and no expansion joints. The slab is probably five inches thick. There is very little traffic. It was laid in 1915. Longitudinal cracks have developed and the pavement is not in good condition. Both longitudinal and transverse joints should have been provided.

In Tulare County on the road between Exeter and Lindsay, near Burr Station, the pavement is sixteen feet wide, five inches thick, made of a 1-3-6 concrete. It is surfaced with one and one-half inches of asphaltic concrete. The soil is adobe. Cracks in the soil of adjacent fields were from an inch to an inch and a half wide and thirty inches deep. There are shoulders three feet wide. There are adjacent side ditches about three feet deep in which irrigation water frequently stands. The surface of the pavement is apparently in good condition except for a few expansion transverse cracks. It is stated that the concrete slab had broken down before the asphaltic top was put over it.

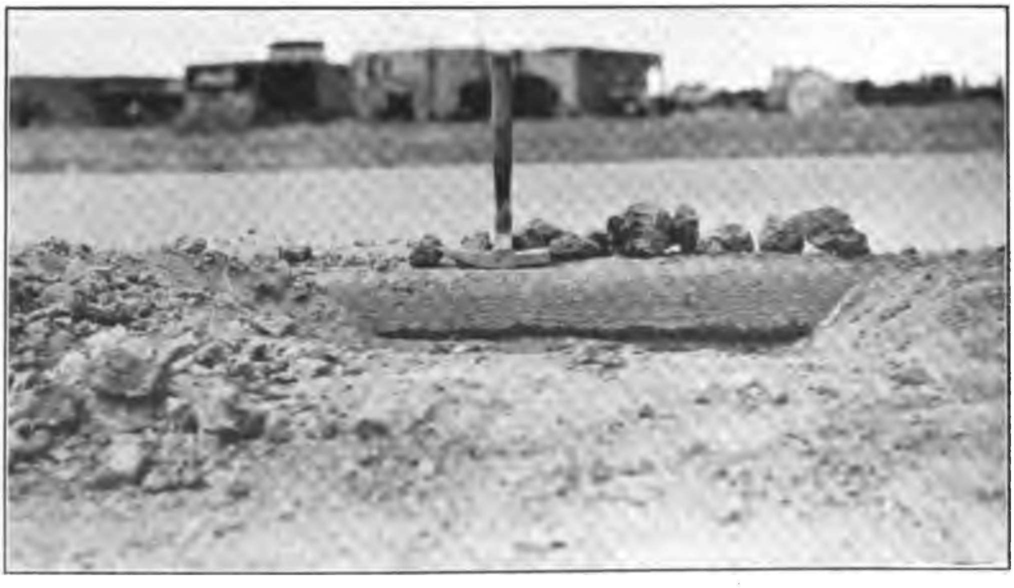
On the same road from Visalia to Exeter, on the Merriman Branch, the concrete is fifteen feet wide and four inches thick without asphaltic surfacing. There are frequent longitudinal cracks and checking on the surface. The soil on which this pavement is laid is better than in the previous instance.

On the Porterville-Worth road a concrete slab was laid for two and one-half miles. It is fifteen feet wide and four inches thick with a 1-2-4 mix. It is broken down badly with longitudinal cracks from an inch to an inch and a half wide, with many random cracks. Some of the concrete blocks were so shattered that they had to be removed. At the end of two years a top of one and one-half inches of asphaltic concrete (Topeka) was put over it. The pavement is now in fair condition after one year's additional service. Some of the longitudinal cracks show through the top surfacing. No reinforcing was placed in the concrete.

Mr. Lawrence Moye, the county surveyor who has charge of the building of these roads, states that while there is much alkali in Tulare County, he has never seen any pavement in which the concrete appeared to be broken down by its action. One of the best sections of four-inch highways in the County is on the Tipton-Woodville division. It shows transverse cracks about 130 feet apart for a distance of over 1,000 feet, and no longitudinal cracks. This is over the worst alkali on the division.

Ten experimental types of pavement were built on Sacramento Avenue in the Washington Subdivision on the west side of the Sacramento River, opposite the city of that name. These slabs were made of various thicknesses, from four to six inches, and were reinforced in various ways. The soil on which they were laid is classified by the Bureau of Soils as Sacramento clay. These pavements have been in service for eight years. The traffic has been moderate except during the harvest season, when heavy loads of grain and rice are hauled over it on iron shod wheels. Where reinforcing was used the cracks are not so wide as where it was not used. One experiment is interesting in that a longitudinal construction joint was made in the center of the pave-

9-1 Taken in connection with 8-10 showing pavement broken down due to shrinkage of subgrade, Imperial County.



8-10 Shrinkage of clay soil subgrade leaving pavement unsupported, Imperial County.

ment. This joint was filled with oil. It has opened up and become three inches wide. The concrete was good and sections of it are in perfect condition. It was noted that the portions of the pavement which failed the most were where standing water occurred near the sides of the slabs during the winter. One section having good drainage ditches on each side four feet below the top of the slab is in good condition. This portion of the pavement, however, was laid on an an old turnpike. There are ten of these experimental slabs, and after an examination extending over some two or three hours, it was difficult to draw any particular conclusions from the tests save that where the drainage was good and where the slabs were laid in slight cuts on ground that was slightly above average elevation, it was in better condition. Its present condition depended more on the sub-base and drainage than on the mixture of concrete or reinforcing. Reinforcing was beneficial in holding the fragments of the slab together.

In Sacramento County, on what is known as the Lower Stockton Road, the soil is classed by the Bureau of Soils as Alamo clay. In this case a loam soil was hauled in as a top for the subgrade for a thickness of six inches. This top soil is called a Madera loam. The subgrade was puddled by flooding in October and November. It then stood until June 1st of the following year. The surface was then again treated with water until it was moistened for six inches. It was then re-rolled and upon it was then placed a fifteen-foot slab, four and one-half inches thick, reinforced with wire mesh. No bars were used. The mixture is 1-2½-5, crushed gravel being used. Longitudinal cracks prevail for about twenty-five per cent of the length of the road about three feet from the edge. They are about one-quarter of an inch or less in width. The concrete is good. Traffic is light. The age is two years. Other than the longitudinal cracks noted, the pavement is in good condition.

In San Joaquin County, north of Stockton, there is an asphaltic concrete road built on "Stockton Adobe Clay." The pavement is from ten to fourteen feet wide, **laid on six inches of gravel which was rolled into the adobe subgrade.** The slab was originally four inches thick. It was laid about 1910. There are good drain ditches on the side of the road. The traffic is heavy. The pavement on the northerly section of this road is said to have had little repair. It is somewhat wavy, so that an automobile does not run smoothly over its surface. The southern end of this road was resurfaced with an asphaltic top and widened in 1918. It is in good condition.

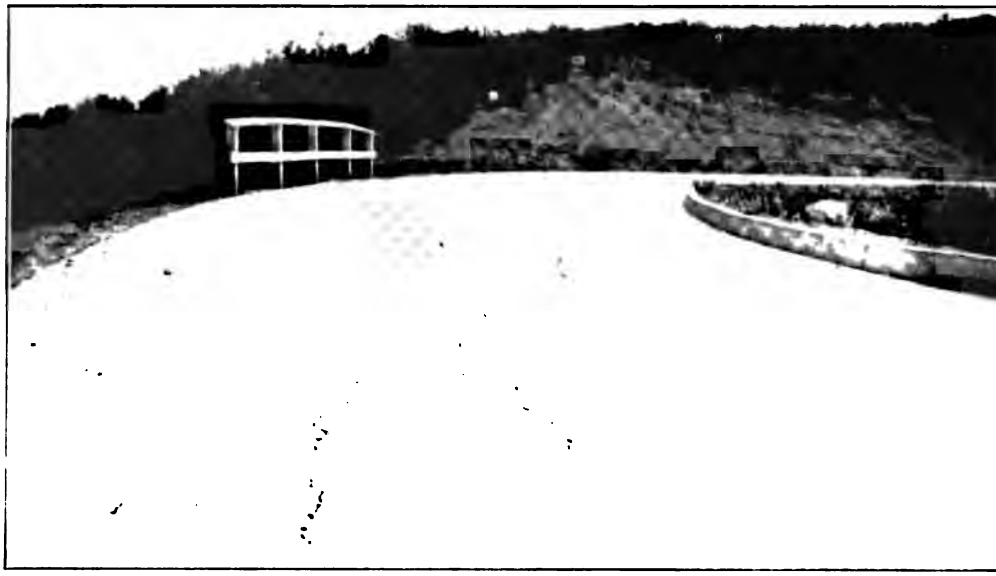
The successful construction of a subgrade between Newman and Patterson, in Stanislaus County, with adobe soil, is described on page 112. This work was very carefully done and the pavement is in good condition.

On the San Juan grade, north of Salinas, there is a standard state concrete pavement, but with oil macadam shoulders. The soil is adobe. Traffic is heavy. No longitudinal cracks have developed in the pavement. The side drainage is poor. The shoulders were made with quarry waste mixed with oil and cost approximately $1,300 per mile. They are four inches thick. One-half gallon of oil was used per square yard.

On the State Highway south of Salinas, known as Section B, there originally was a macadam road fifteen feet wide from four to six inches thick. This old road was shaped up and rolled and a fifteen-foot concrete slab four inches thick laid thereon in 1915. Shoulders made of quarry waste were added. They are four inches thick placed in the spring of 1916. The material is water bound. These shoulders failed under traffic in about one year, and in 1918 they were replaced with oil macadam. The soil on which the road is built is adobe. There are drain ditches. There is no reinforcing in the concrete. Traffic is very heavy, but no longitudinal cracks have developed in the pavement.

The shoulders in the two instances mentioned above are in good contact with the concrete slab. They extend the width of the driving surface of the road so as to greatly improve it.

To the south of this section, where the pavement is directly on an adobe but where no shoulders have been used, there are many longitudinal cracks.



Longitudinal and random cracking 10.2 miles north of Castaic School, "Ridge Route," Los Angeles County. Pavement one year old laid with day labor.

Longitudinal cracks extending into cut mile 11.0 north of Castaic School, "Ridge Route," Los Angeles County. Pavement one year old laid with day labor.

On this same road, in Section C, there is an adobe soil for a distance of two miles. Salinas River sand was harrowed and rolled into the adobe before the slab was placed upon it. Traffic is heavy. There are no shoulders on this pavement. No longitudinal cracks have opened up and the present condition of the pavement is good.

In Section D, to the south, where hard altered shales have been rolled into the adobe, the result has been beneficial.

The pavements of western Washington are in good condition. The foundations on which they are laid are remarkably favorably. Where their roads are built on new clay soils they show much the same distress that is found in California on similar soils. Where they are laid over old macadam roads, having good drainage, they are in good condition. Elsewhere in this report there is given a further description of the Washington State roads.

Elsewhere in this report there is presented data relative to some experimental pavements in Northwestern Oregon. Attention is called to the failures of several types of good, standard construction on clay loam soil with very heavy traffic, when drainage was not carefully provided for. The following notes indicate the importance of sub-base conditions.

On the Tualintan Valley Road near Beaverton there is an hydraulic pavement laid on a clay loam soil. The slab is 16 feet wide, 5½ inches thick on the side, and 6½ inches thick in the center, made with a 1-2-3½ mix. The age is two years. The traffic is not very heavy. Where this pavement was laid on a new grade there are some longitudinal cracks and broken corners. Most of these cracks developed within 90 days after it was opened to traffic. The gravel used in the concrete is said to have been inferior. On other portions of this road which had been laid on an old macadam sub-base the present condition of the pavement is good.

Many of the old macadam pavements in Oregon that have been resurfaced with two inches of asphaltic concrete top, where the drainage is good, show fine condition at present.

On the Bertha Section of the Hillsboro Road the subgrade is a heavy clay. This pavement was built in 1919. There was no macadam sub-base. A two-inch asphaltic wearing surface was placed on a three-inch "black base." There are macadam shoulders two feet wide on the sides. This road is failing. It has been repaired four times in one year. In April, 1920, 105 patches were counted in 1.2 miles.

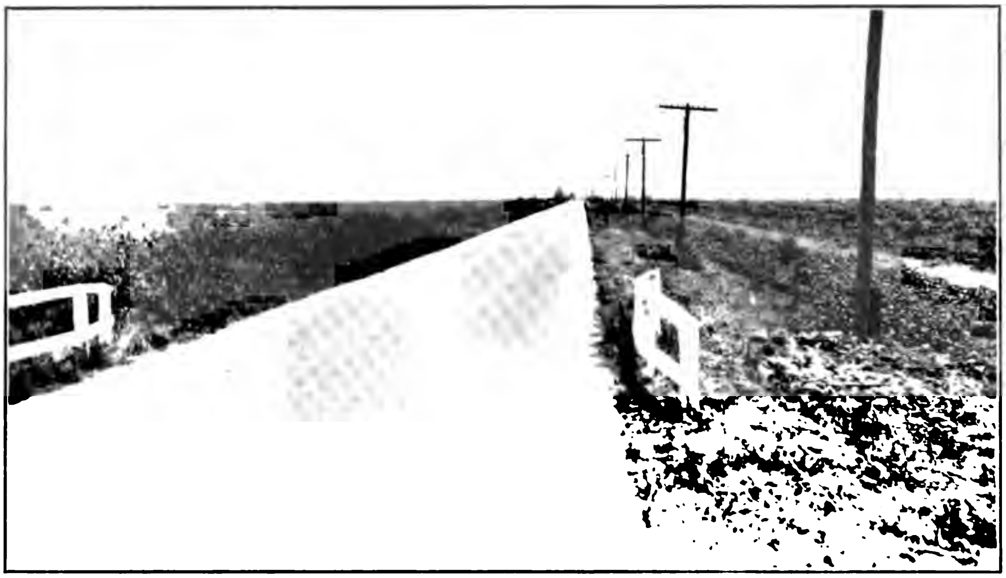
On another portion of this highway there is a five-inch macadam base with the same asphaltic covering. This portion of the road is in much better condition.

On the Capital Highway from Bertha to Washington County line there is a section of four miles built during the years 1915-1916. It is 18 feet wide. The concrete slab is 5½ inches thick on the side and 6½ inches in the center, with a flat base, the crown being 1 inch. The mixture was 1-2-3, using a good crushed stone. The sub-base was from ten to fourteen feet wide of old macadam road in poor condition, resting on a heavy clay soil. There are no sub-drains and the side ditches are inadequate. The cuts and fills were made a year before the paving was placed thereon where there was a change in grade. The two-foot shoulders of broken stone were in poor condition. In April, 1920, from three to four inches of broken stone were added to the shoulders in some places. This road has armored transverse expansion joints at 30-foot intervals. The road has a fairly heavy traffic. Its present condition is good.

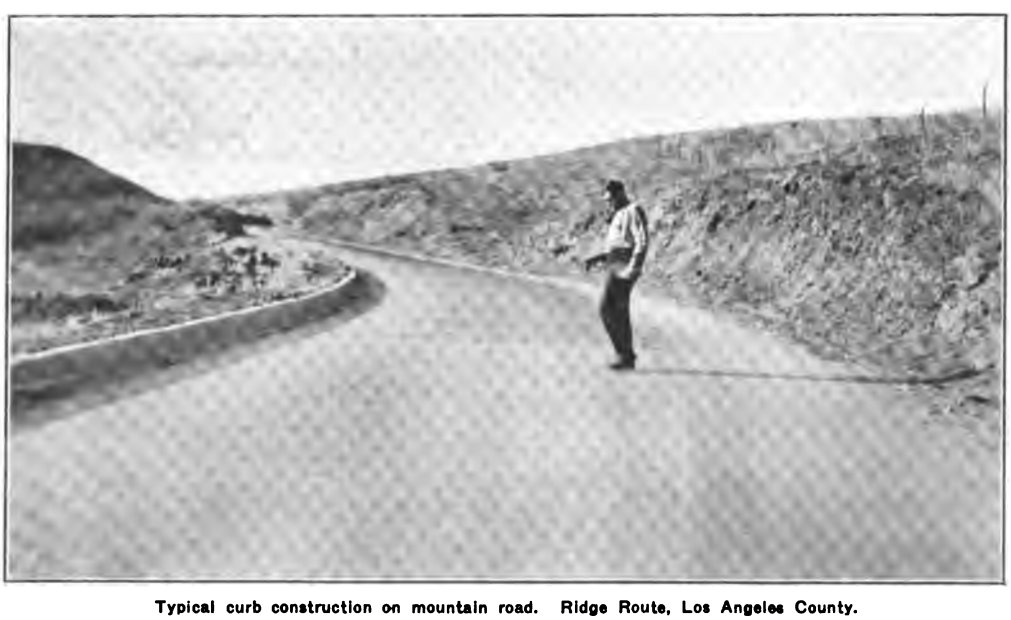
On the west side highway from the Multnomah County line towards Newburg, 15.8 miles of pavement were built during the seasons of 1917 and 1918. The width of the road is 16 feet, two inches of asphaltic concrete was placed on an old macadam which was about six inches thick. This macadam was scarified and re-rolled with considerable rock added. At the time of re-dressing about ten cubic yards were used per hundred feet of road. The sub-soil is a heavy clay. Some tile drains were used, but not enough. This road has been extensively patched and the maintenance is said to have been heavy. About nine per cent of asphalt was used in the mixture, which is said to have been too much, as the road is soft in warm weather, requiring sanding. The

A Pacific Highway, Washington State, 9 miles southeast of Chehalis. Longitudinal crack on new concrete pavement which had been laid on clay soils.

J Columbia Highway above Portland showing character of dry rubble wall and guard rail frequently found along the route.



Typical concrete shoulder construction, Orange County. This shoulder was added when pavement was but 4½ years old.



Typical curb construction on mountain road. Ridge Route, Los Angeles County.

shoulders are usually of broken stone. This pavement shows distress and is wavy. Some sections, however, are in good condition. It is estimated that the repairs now required on the road will average about $200 per mile.

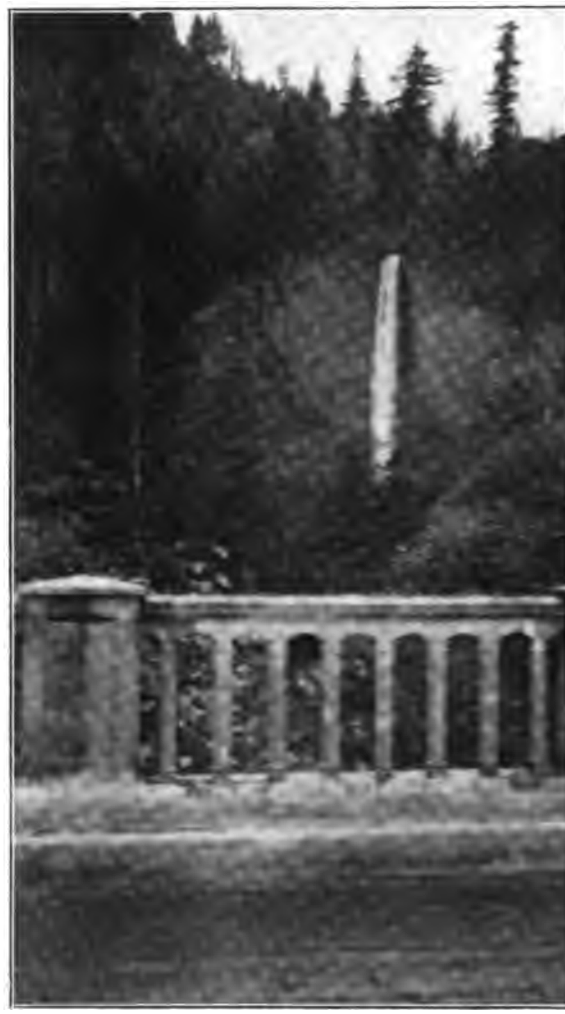
The Columbia Highway above Portland, to Multnomah Falls, is 35 miles in length. It was built in 1915 and 1916 by a bond issue by Multnomah County, Oregon. The road is mostly located on the side-hill with rock near the surface. The prevailing shallow soils are clay loams. Great care is taken with drainage, concrete gutters usually being built on the uphill side and the water led under the pavement through catch boxes and tile drains. The foundations are therefore excellent. Up to the present time (1920) there is little truck traffic on this road, but as many as four to five thousand automobiles pass over it on some holidays. It is 18 feet wide on tangents and broadens to 20 feet or more on curves. The sub-base averages about six inches of crushed open rock. In some places where the foundations are bad this rock filling is thicker. There was a paint coat of asphalt placed on top of the rolled stone. The road has a two-inch wearing surface of asphaltic concrete, with a finish coat of fine stone and screenings rolled with about three-fourths of a gallon of bitumen per square yard.

From Portland to the Automobile Club House on Sandy River, for a distance of 20 miles, the asphaltic concrete was placed on an old macadam road from 8 to 10 inches thick, over which from three to four inches of additional rock was rolled. The balance of the road was laid on new grade. The curves have a maximum radius of a hundred feet with a maximum grade of 5 per cent compensated. The roadway is thirty feet wide. The super-elevation on the outside of the curves in places is as much as thirty inches. There are concrete curbs on each side of the curves. Outside of the curve on the hillside is a concrete gutter. On the outside of the curves where there is a downhill drop-off there is a railing made of posts 8 inches by 8 inches by 8 feet long set four feet in the ground. The portion of the post set in the ground is creosoted. There are two rails attached to these posts made of 3-inch by 8-inch board. In many places stone walls are on the outside of the road. The condition of this road is excellent. The contractor gave a five-year surety bond to maintain it, with an additional five-year personal bond. The average cost of this road for grading was about $25,000 per mile, and the pavement cost approximately an additional $22,000 per mile, a total of $47,000. This is a most beautiful road. The views are spectacular and wonderful. It follows the left bank of the Columbia River, passing cascades and waterfalls. The highway often issues from densely timbered areas on to high, overlooking bluffs with commanding views. Much of the most attractive property along it has been acquired by individuals and given to the county. The public lands are included in a forest reserve. There is no park in America that equals it. The few photographs attached, lettered from C to I, pages 135-6, give but a faint impression of the charm and grandeur of this scenic highway.

The inspection of the Washington and Oregon Roads was instructive. They demonstrate that concrete pavements, where placed on natural sand and gravel soils, having good sub-drainage, as is found in many portions of western Washington, will stand heavy traffic without failure, but where they are placed directly on new grades composed of clay soils these pavements will show much the same kind of distress as experienced in California. In northwestern Oregon, where the prevailing soils are of a clay type, all classes of pavement that are built directly upon them have failed, particularly as indicated by the experimental sections on the Columbia Highway below Portland. Around Portland, however, where old macadam roads have existed over which traffic has passed for years, even on the worst soils, either hydraulic cement concrete or asphaltic concrete of the standard sections now adopted will successfully stand heavy traffic provided drainage conditions are good. These roads indicate that pavements placed on the adobe soils of California, provided they are well drained and covered with a layer of macadam or gravel well rolled into it, should stand heavy traffic with fair success. Experience, as well as theoretical discussion, in California has proven that it is bad practice to build either a rigid concrete slab, or any other known type, on an adobe base that will expand and contract with changing moisture content.

The authorities in Oregon have used much asphaltic concrete materials for pavements. The Columbia Highway is a notable example. Apparently the State and county engineers have an

G Columbia Highway above Portland showing gutters to remove water from side hill.



H Columbia Highway above Portland showing attractive type of bridge and view of one of numerous waterfalls.

I Columbia Highway above Portland showing type of bridge. Each is a special design of varied artistic detail.

C Logging load on Washington pavements, local weight 24,000 pounds on four wheels.

open mind relative to the merits of either cement or asphaltic types for localities where the foundations were good, as in the case of putting a new surface on an old macadam road. Where poor foundations occurred some of them expressed themselves as preferring hydraulic cement concrete pavements. In Washington State, however, concrete pavements are quite universally accepted for all types of sub-base and service.

RECOMMENDATIONS

Soil Study

1. A study of soil conditions along any routes that it is proposed to pave should be made by the engineer. These should be classified so as to show separately the sand and gravel soils, those that are of loam and also the adobes and clay types. Much greater care is necessary in the preparation of the sub-grade and in the strengthening of the slab on the clay and adobe soils than on those that are sand and gravel and therefore better drained. Field samples of soil should be taken along the line and laboratory experiments made to determine the shrinkage and expansion of the various types encountered, with a view of determining the best method of treatment of the sub-base and slab. In the event that the sample shows dangerous expansion and contraction, the experiment should be continued by blending sand and stone with the clay to determine whether this may be obviated by such process.

2. Where the soils encountered are clays and adobes, the sub-base should probably be blended or adulterated by rolling broken stone, sand and gravel into it, in order to obtain conditions approaching those that would obtain in case an old macadam road had originally been built thereon.

Fills

3. When it is necessary to make fills along portions of the line where adobe is encountered, it is desirable, if at all feasible, that these should be built of selected materials other than adobe, in order to avoid changes in volume. If good quality of soil is not available for fills, the heavy earth fill should be built up in layers. If they are made of sand or sandy loams, they should be sprinkled, but in case they are built of clay or adobe, it is recommended that they be handled dry. After the fill has been brought to grade it should be surfaced with some suitable road metal and traffic turned over it. They should be allowed to stand through one or more rainy seasons, depending on their height. Levels should be taken thereon at fixed intervals of time and until no further settlement can be observed. Not until then should the pavement be placed on the fill.

Sub-grade

4. The sub-grade, particularly on heavy soils, should be prepared with especial care so that it will be compacted into the smallest space for the entire width of the road, including that portion which will be under the shoulders. With the heavier types of soils, the sub-grade should be built up in layers from 6 to 12 inches thick which are rolled into the smallest possible space. The sub-grade, including the shoulders at least two feet beyond the edges of the proposed pavement, after completion should be such (unless it be composed of sand) that repeated trips of a 12-ton three-wheeled roller will show no indentation of the surface and bear up, without deformation, under the wheels of heavily loaded trucks or wagons. It has been demonstrated that it is possible to so construct subgrades of heavy soil that shrinkage is so minimized that a concrete slab laid thereon is not seriously broken under heavy traffic.

Shoulders

5. The clay and adobe subgrades shrink in drying to the greatest extent along the edges of the pavement, leaving them frequently unsupported. This results often in the failure of the slab when it is loaded. It is noted that this shrinkage extends for a distance of from three to four feet under the slab where impervious shoulders have not been provided. Only 6½ per cent of these in Southern California have been constructed to date. Where impervious shoulders have been provided and adequately maintained, they not only substantially extend the effective width of the pavement for the accommodation of the traffic, but they reduce the changing of moisture content under the edges of the concrete slab. These shoulders, being flexible, are not ruptured by the change in volume of the sub-base beneath them. They should be made simultaneously with the construction of the pavement and before the slab has failed.

Failure of concrete road north of Goleta over adobe fill, Santa Barbara County.

Longitudinal cracking over adobe soil north of Goleta, Santa Barbara County.

Drainage

6. On clay and adobe soils drainage is essential. On sidehill work, drain ditches excavated eighteen inches in depth should be filled either with broken stone or tile and the water carried away from the base of the pavement. A uniform moisture content cannot be maintained in a sub-grade when pools of water occasionally stand along the sides of the pavement. In sandy or loam soils the grade may be held down to within a few inches above prevailing ground levels. On heavier soils, however, it should be raised to at least twelve inches above the general ground levels.

Experiments

7. The prevention of shrinkage and expansion in clay or adobe soils under a rigid pavement is beset with such uncertainty and is so essential to the permanence of any type of pavement that it is of great importance that both laboratory and field experiments should be made by the State to determine the most effective manner of accomplishing this. The method by which clay soils absorb and evaporate moisture should be studied, together with the volume of shrinkage or expansion and the forces that are exerted thereby. A continuing series of levels should be taken on pavements that are now laid on adobe sub-soils in order to determine the amount of movement that occurs.

As the road construction program of California on the part of the State and Counties involves a past and prospective outlay of over one hundred million dollars, and as so many of the problems involved, both with reference to the subgrade and slab, are yet not completely solved, it is important that extensive laboratory and field investigations should be undertaken under the direction of the Highway Commission or by some adequately equipped organization, such as might be obtained in the Engineering Department of the State University. Road problems are encountered in California which are unique. It is not adequate for the investigations to be carried out by the Federal Good Roads Bureau in the East. Such studies should be conducted through a term of years. They particularly should include methods by which the moisture contents under the pavements could be kept uniform. While investigations of this nature have been started in the laboratories of the State University for this report, time has not been sufficient to carry them to the desired finality.

Inspection

8. No specification for a sub-base will be satisfactory unless it is rigidly enforced in the field. To some contractors much of the detailed procedure which involves expense to them is deemed unnecessary and unduly exacting, and there may result a continued pressure to avoid the performance of some of the requirements. It is, therefore, necessary that the work on subgrade should be inspected with vigor and exactness, because the whole future life of the pavement rests on the adequacy of the subgrade.

Expenditures

9. The average cost per mile of State roads in Southern California to date has been $18,097.00. It has been found that the average annual cost per mile of maintaining, widening and resurfacing these roads amounts to $615.00. When to this is added the average interest costs and bond retiring fund, the total mean annual expense per mile for these roads to the people of the state is $1,353.00.

Experience has shown that all types of roads, including certain experimental sections that have been built with unusual care and stability, have failed under heavy traffic when placed on poor subgrades, and that even the lighter types of pavements, when placed on good foundations, have given quite satisfactory service. It follows, therefore, that heavy expenditures are justified in the preparation of the subgrade; and in fact that no type of pavement should be built on heavy, undrained soil until it is put in satisfactory condition, irrespective of cost.

(Signed) ROBT. MORTON, Chief Engineer,
San Diego Highway Commission.

LAWRENCE MOYE, County Surveyor,
Tulare County.

J. B. LIPPINCOTT, Consulting Engineer.

Low shoulders and ravel at edge of pavement near Encinitas, San Diego County.

Triangular breaks in wide pavement in the City of La Jolla, San Diego County.

REPORT OF THE COMMITTEE ON THICKNESS, WIDTH AND REINFORCEMENT OF CONCRETE SLAB

MR. CHARLES PETIT, County Engineer, Ventura County, Chairman
PROF. CHAS. DERLETH, Jr., Dean of Civil Engineering Department, University of California, Berkeley
MR. OWEN O'NEILL, County Engineer, Santa Barbara County

(a) The Committee on "Thickness, Width and Reinforcement of Concrete Slab" has made a field inspection of concrete pavements in Monterey, San Luis Obispo, Santa Barbara, Ventura, Los Angeles, Orange and San Diego Counties in Southern California. Some members of the committee also made an inspection of selected sections of concrete paving in Alameda, Contra Costa, Solano, Sacramento, San Joaquin and Stanislaus Counties in Northern California. Highways in Oregon and Washington were also visited. The inspection in the Southern California counties covered both State and county highways and included plain and reinforced pavements. The cross-section and manner of reinforcing some sections of pavement examined are contained in Appendix "A" to this report, page 149.

From this field inspection and from a study of the available literature on the subject of reinforcement, thickness and width of slab, the committee makes the following observations and recommendations:

(b) The most serious defect of the concrete pavements examined, but not the only defect, is the ocurrence of cracks in the concrete. The reason that cracking is considered a most serious defect is discussed later in the report. Cracks of the most common occurence may be classified as follows:

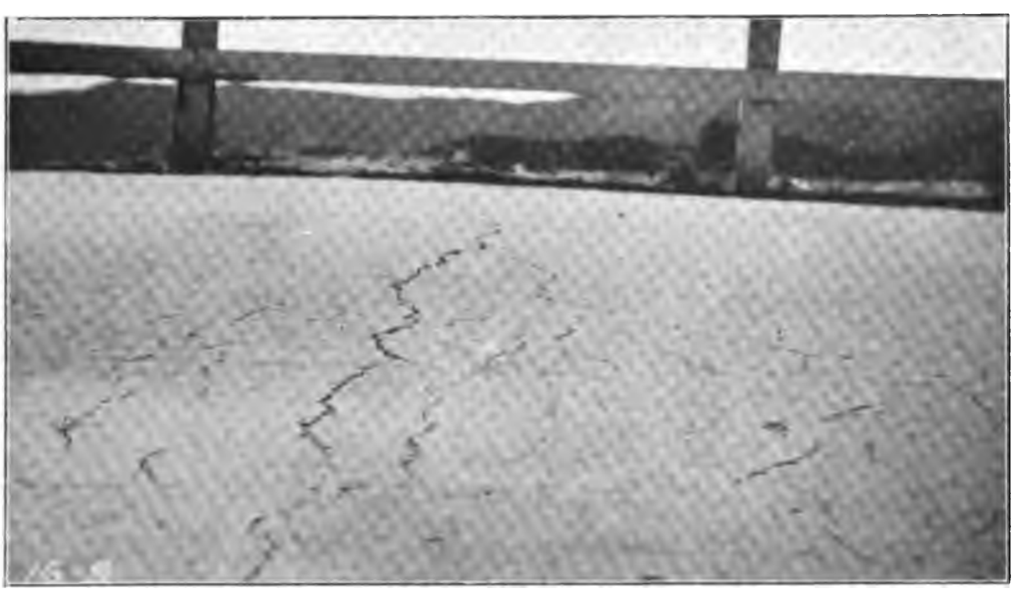
1. Transverse cracks roughly at right angles to the center line of the pavement.
2. Random cracks, sometimes called "Surface Cracks" or "Hair Cracks."
3. Cracks surrounding circular or irregular spots where the pavement slab has settled under load.
4. Longitudinal cracks, roughly parallel to the center line of the pavement.
5. Diagonal cracks or corner cracks occurring where the transverse cracks or expansion joints intersect the edge of the pavement slab.

(c) **All cracks in concrete pavement as classified in Section b of this report, are caused by tensile stresses in the concrete.** Theoretically, cracks could be caused by direct shear of compression under excessive load, but to get this kind of failure it would be necessary to have an unyielding subgrade. Otherwise the slab would yield sufficiently to produce tensile stresses which would be the ruling factor in the formation of the crack. An exception to this should be noted where breaking by direct compression occurs at the edge of the concrete slab, or adjacent to an unprotected expansion joint. This kind of failure manifests itself in the breaking of small fragments of the slab, which disintegrate into the original aggregate by raveling, rather than in the formation of pronounced cracks.

Tensile stresses in the concrete slab are set up by (a) temperature, (b) drying of the concrete, (c) beam and slab action under the dead and live load, (d) heaving of the subgrade under the pavement.

(d) **Transverse cracks in narrow concrete pavements are caused by a combination of temperature and setting stresses.** The formation of these cracks can be eliminated by placing sufficient expansion joints in the pavement when it is laid. While the committee does not consider a transverse crack to be a serious defect in the pavement, yet we would advocate the use of expansion joints, especially for slabs thicker than four inches. We do not favor especially designed or armored joints, a plain joint with asphaltic filler being sufficient. We consider the constructed expansion joint preferable for the following reasons: (1) It presents a better appearance by the regular intervals and straight lines. (2) The intermediate cracks between the regular joints of about thirty-foot intervals are merely hair cracks. (3) An

General view of road near Elwood, Santa Barbara County.



Intensive random cracking 7 miles north of Castaic School. "Ridge Route." Los Angeles County. Pavement one year old, constructed by day labor.

irregular crack such as is formed where no expansion joints are provided invites raveling at the numerous small, irregular angles and corners formed along the crack. (4) In case of the thicker slabs the crack will not be in a true vertical plane, but will have the same irregularities in the vertical directions that are apparent in the horizontal. This will allow small fragments of the slab to be broken down under traffic adjacent to the crack under cantelever action, and is another fruitful source of raveling.

The committee does not recommend that reinforcing steel be placed in the pavement with the object of preventing transverse cracks. It would, however, emphasize the necessity of proper protection and maintenance of transverse cracks by keeping them filled and the adjacent edges of the slab covered with an asphaltic cement, or similar material.

(e) **Random cracks, otherwise called "Surface "Cracks" or "Hair Cracks," have their initial formation when the concrete takes its set.** It is our observation that cracks of this kind continue to grow in length, width and depth under traffic. They constitute a distinct defect in a concrete pavement, in that their presence breaks up the monolithic structure of the slab, and thereby decreases its carrying capacity through slab action. Furthermore, unless such a pavement is protected by a wearing surface of asphaltic mixture excessive abrasion and raveling will occur at the edges of these numerous cracks that will ultimately lead to the destruction of the pavement. An added danger from this kind of cracking is that moisture is thereby allowed to reach the subgrade and weaken its supporting power for all classes of soil except sand and gravel. In localities with more severe winter weather than Southern California this moisture would become an active agent of destruction through freezing and thawing.

The committee is of the opinion that this kind of cracking is not dependent upon the thickness of the slab, nor that it can be prevented by the use of reinforcement. While it would be possible to limit the growth of these cracks under traffic by placing a wire mesh reinforcement near the surface of the slab, we are strongly of the opinion that methods should be adopted to prevent their occurrence when the pavement is laid.

The science of concrete road building has not advanced to the stage where all of the causes of surface cracks can be definitely listed. We would, however, recommend that precaution be taken against the following causes which are known to have a direct bearing on the formation of surface cracks.

1. The use of dirty sand in the aggregate. Under this head we would class sand containing humus or organic matter or sand containing in excess of 5 per cent of fines passing a 100-mesh sieve. For the detection of humus we would recommend the sodium hydroxide test as described in Part 1 of the 1917 Proceedings of the American Society for Testing Materials, pages 327-333. (See Appendix "B" to this report, page 154.)

2. The picking up of the earth of the subgrade with the concrete aggregate. This will occur when the aggregate is dumped directly on the subgrade. If the broken stone or gravel is deposited on the subgrade, we would recommend the use of stone forks rather than scoops in picking it up, or that the piles be shoveled from the top and the bottom layer of stone be left.

3. Allowing the concrete to dry out too rapidly in curing. This will occur on days of high temperature or during dry winds. The recommended practice in this case is covering with canvas until the concrete has taken its final set. (See Appendix "F" for references on this subject, page 157.)

(f) **Cracks surrounding irregular depressed spots in the pavement are caused by failure of the pavement under load when acting as a true slab.** This kind of failure presupposes a yielding or a depressed subgrade. Tests made by Mr. Goldbeck for Bureau of Public Roads on the distribution of concentrated wheel loads to the subgrade by the concrete slab ascer-

Longitudinal cracking and disintegration of pavement east of Ventura, Ventura County.

Longitudinal cracking and disintegration of pavement east of Ventura, Ventura County. Pavement 2.9 years old.

tained the fact that the concentrated load was distributed by an 8-inch slab over an area having a radius of 4 feet. (See Public Roads, Vol. 1, No. 12, page 37.) For a paving slab of 5 or 6-inch thickness this radius would not be over 36 inches.

Following the analysis developed by Mr. Goldbeck, we have calculated the tensile stress in the concrete that is developed by a 10,000-pound wheel load, for a yielding subgrade. This unit stress for different thickness of slab is as follows:

4 inches—326 pounds per square inch
6 inches—146 pounds per square inch
8 inches— 80 pounds per square inch
10 inches— 52 pounds per square inch
(See Case 1 in Appendix "C," page 154.)

Assuming that the tensile stress in concrete should not be over 10 per cent of the compression stress, 150 pounds per square inch would be a safe working stress in tension. It would appear, therefore, that a 4-inch slab would not be safe in this case, but that 6 inches is the minimum thickness that would be justified.

Calculation of the stresses in the slab over a depression in the subgrade of 36-inch radius gives stress twice as great as listed above, in which case even a 6-inch slab unreinforced will not be sufficient. The committee is of the opinion that relief from this latter kind of failure should be sought through proper treatment of the subgrade rather than by increasing the thickness of the slab.

(g) **Longitudinal and diagonal cracks are a distinct defect** in a concrete highway, and they constitute the most prevalent kind of failure in all of the concrete roads examined by the committee. This form of failure is not confined to a few isolated locations, but was noted on many miles of State and county highways.

The formation of diagonal or corner cracks and longitudinal cracks in a paving slab is due to stresses developed by cantilever beam action under load. To get such action, a condition of subgrade is presupposed in which there is little or no support given to the edges of the concrete slab. This is a condition which has been found to exist with many miles of concrete pavement laid on clay or adobe soil. The property which such soils have of changing volume with the percentage of moisture contained is well known. Professor Hillgard in his book on Soils (see Hillgard—"Soils," Edition 1914, page 113) notes examples of adobe soils that shrank from 28 per cent to 40 per cent by volume in drying. A shrinkage of 30 per cent by volume is equivalent to a shrinkage of 11.2 per cent in one direction. Measurements of shrinkage of adobe soil made by the committee in the field showed a lateral shrinkage of 10 per cent to 15 per cent. Vertical cracks in the same soil extended to depths of 20 inches or more and the soil was thoroughly dry to that depth. The same percentage of shrinkage in a vertical direction as in a horizontal would therefore indicate that the subgrade at the edge of a concrete slab had shrunk at least two inches vertically from the bottom of the slab. Measurements made in the field showed that this drying and shrinking extended from 3 to 4 feet under the edge of the slab. Assuming a plain paving slab unsupported for 26 inches from the edge, and under a 10,000-pound wheel load with impact, we have calculated the safe thickness to be 14 inches for the stresses that would cause corner diagonal cracking. Under the same conditions, the thickness necessary to withstand longitudinal cracking is 20 inches. In this calculation we have assumed 150 pounds per square inch as a safe working stress of 1-2-4 concrete in tension. (See Appendix "C," cases 3 and 4.) While it may appear that this unit stress is too low, we would note that for the impact factor we have used only 100 per cent, whereas Mr. Goldbeck in his tests on impact determined factors of 300 and 400 per cent. It is therefore evident that relief from this kind of failure on clay or adobe soils cannot be obtained by increasing the thickness of the slab of plain concrete, within economical limits.

Crescent-shaped longitudinal crack mile 6.7 north of Tulare, Tulare County.

Typical triangular break mile 9.6 north of Tulare, Tulare County, at transverse cracks.

For the same condition of loading and support we have calculated the stresses in a 6-inch reinforced concrete slab. We find that for a working stress of 20,000 pounds in the steel there would be required one-half inch bars at 2-inch centers transversely. This, however, would give a stress of 2,850 pounds per square inch in the concrete in compression, which is beyond the safe limit. For an 8-inch slab we find the steel required to be one-half inch square bars at 2.85 inches centers and the stress on the concrete to be 1,360 pounds per square inch.

We are therefore of the opinion that the amount of reinforcement which it is practical to place in a paving slab of six or eight-inch thickness, when laid on this character of soil, will not hold the edges of the pavement in its original position and prevent cracks. Tests made by the City of Seattle on concrete beams of various thicknesses and reinforcement show that a plain beam 7¾ inches in thickness will carry a greater load than a 6-inch beam reinforced with 35 to 45 pounds of steel to 100 square feet of surface, as is common practice in California. (See page 156A.) These small amounts of reinforcing, however, allow the paving slab to settle and remain in contact with the subgrade without the formation of large cracks in the pavement. We consider this to be the chief function of reinforcing steel in the concrete slab.

For soils of this character we would recommend that additional measures be taken to reduce this vertical movement of the subgrade to a minimum. Among these would be:

(1) Adulteration of the subsoil with sand, gravel or cinders to overcome the tendency to change in volume with change of moisture content.

(2) Construction and maintenance of an oil macadam shoulder four feet wide on each side of the slab to prevent the drying out of the subsoil under the edges of the slab.

(3) Construction of a curtain wall of concrete 6 or 8 inches wide and at least 12 inches deep below the bottom of the slab on each side. Such a wall would prevent drying of the subsoil and also give additional support to the pavement at its weakest point.

The committee is of the opinion that the cost of any measures taken to prevent longitudinal and corner cracks in the pavement, laid over bad clay or adobe soils, is justified, even if it doubles the total cost of the highway. The presence of these cracks indicates incipient failure of the pavement. A corner crack always exposes another corner of the pavement which is subject to the same kind of failure. In this manner a break at a corner grows until it reaches the center of the pavement. A longitudinal crack in a pavement opens a new avenue for moisture to enter the subgrade and to escape by evaporation. This leads to the formation of other longitudinal cracks parallel to the original crack. The entrance and exit of moisture causes alternate swelling and shrinking of the subgrade. The accompanying unequal vertical movement of the slab, with the opening of old cracks and formation of new ones, ultimately brings about complete rupture and failure of the pavement.

(h) **A discussion of the proper width of a paving slab** should take into consideration the safety of the traveling public, the cost of maintenance of the shoulders, and the cost of maintenance of the paving slab. In Appendix "E" we submit a table showing the width, thickness and proportions of aggregate used in concrete road slabs of the various states. A proper width of slab cannot be determined mathematically, but we submit the following arguments in favor of the wider slab, 18 to 20 feet, rather than the narrower slab, 15 to 16 feet.

1. The safety of the traveling public is immeasurably increased by the use of wider slab. Increasing traffic and speed are constantly adding to the risk of travel on the highways, and these two elements of risk can be best compensated by the use of the wider slab.

2. The use of the wider slab will reduce the amount of travel on the shoulder, and especially reduce the amount of traffic running off the slab in passing other vehicles. Wheels running off the edge of the concrete slab are a constant source of damage in the continuous

fracturing and raveling of the concrete at the edge. The increased travel on the shoulders of the narrow slab increases the cost of the shoulder maintenance, and in this case good condition of shoulders is necessary for the proper protection of the concrete slab.

3. Another source of damage to the narrow slab, aside from the raveling at the edges, arises from the fact that heavy vehicles are compelled to keep one wheel practically on the edge of the slab. Our calculations show that a wheel in this position produces the greatest stress in a concrete slab laid on a compressible subgrade, and that this stress is the cause of longitudinal and corner cracks. Observations by members of the committee are to the effect that on a twenty-foot pavement the largest trucks pass each other constantly without bringing their outside wheels nearer than 18 inches to 2 feet from the edge of the pavement. A load 18 inches from the edge of the pavement will only produce one-half the stress produced by a load at the edge under the conditions assumed in our calculations. (Case No. 4, Appendix "C.")

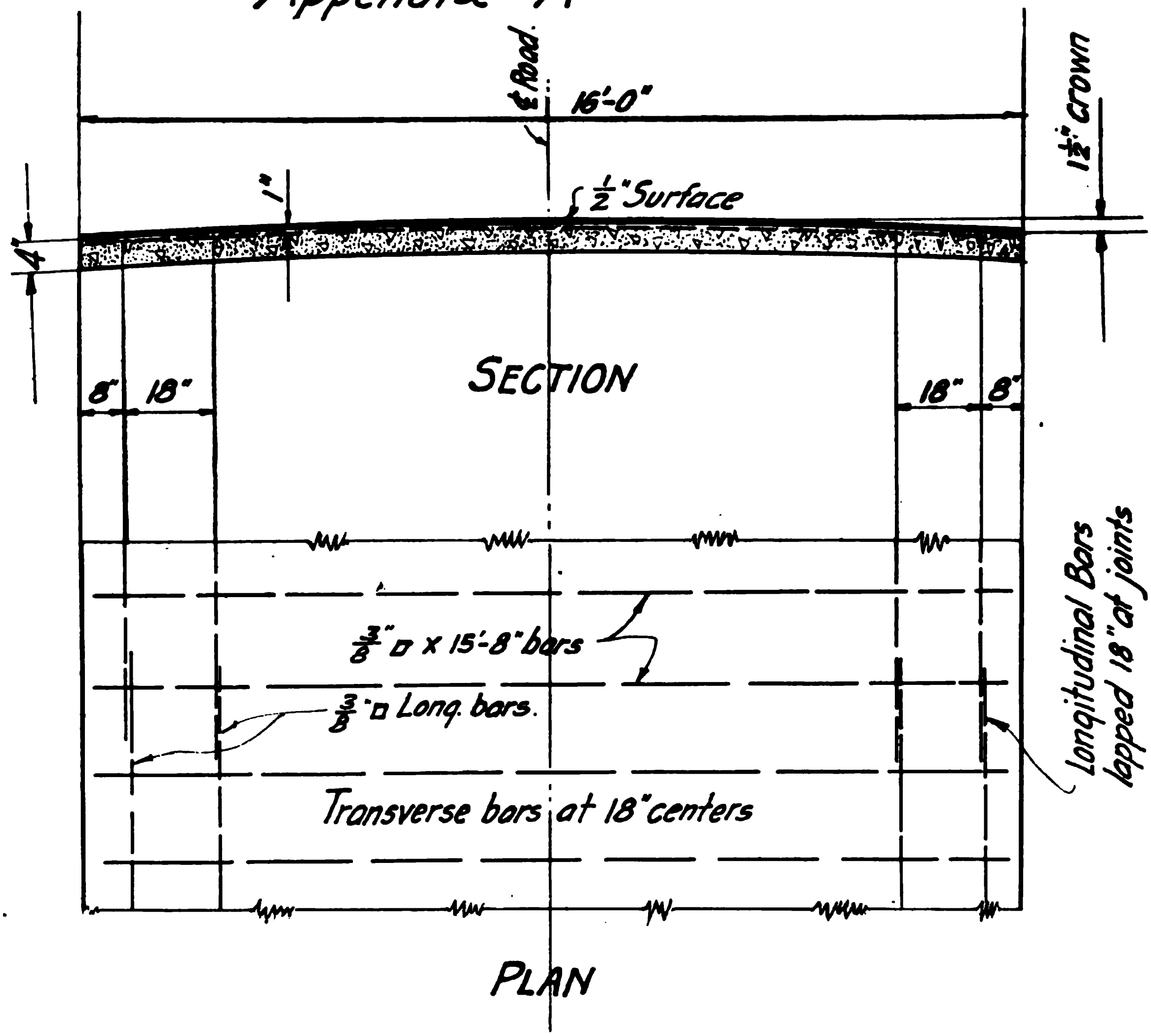
Furthermore, the capacity of the pavement to transmit a load at the edge of the slab to the subsoil is only one-half of the capacity of the slab when the load is back three feet from the edge, because there is effective only one-half the cone of pressure.

(i) **The recommendations of the committee on the width and thickness of slab and amount of reinforcement are as follows:**

1. On sand or gravel subsoil there should be at least a 5-inch slab of plain concrete.
2. On average soil there should be at least a 6-inch slab of concrete usually unreinforced except in localities of unusual difficulty, such as new fills.
3. On subsoils of bad clay or adobe there should be a 6 to 8-inch slab of reinforced concrete.
4. The amount of reinforcing should be the equivalent of ⅜-inch square bars at 12-inch centers transversely with three longitudinal bars of the same size on each side of the pavement at 18-inch centers, the first bar being close to the edge of the pavement.
5. The position of the transverse reinforcing steel should be near the top of the slab, about 2 inches from the surface. The longitudinal steel should be nearer the bottom.
6. On bad clay or adobe soils the adulteration of the subgrade, the oil macadam shoulders, and the curtain walls, should be used.
7. The width of all double track highways, except near cities where traffic is congested, should be at least 18 feet on tangents and widened on curves.
8. The width near cities, where traffic is congested, should be increased to provide for three lines of traffic.
9. All concrete should be of the 1-2-4 quality.
10. Expansion joints should be placed in the pavement when it is laid.

(Signed) CHARLES PETIT,
County Engineer, Ventura Co.
CHAS. DERLETH, Jr., Dean,
Civil Eng. Dept., Univ. of Cal.
OWEN O'NEILL,
County Engineer, Santa Barbara Co.

Appendix "A"

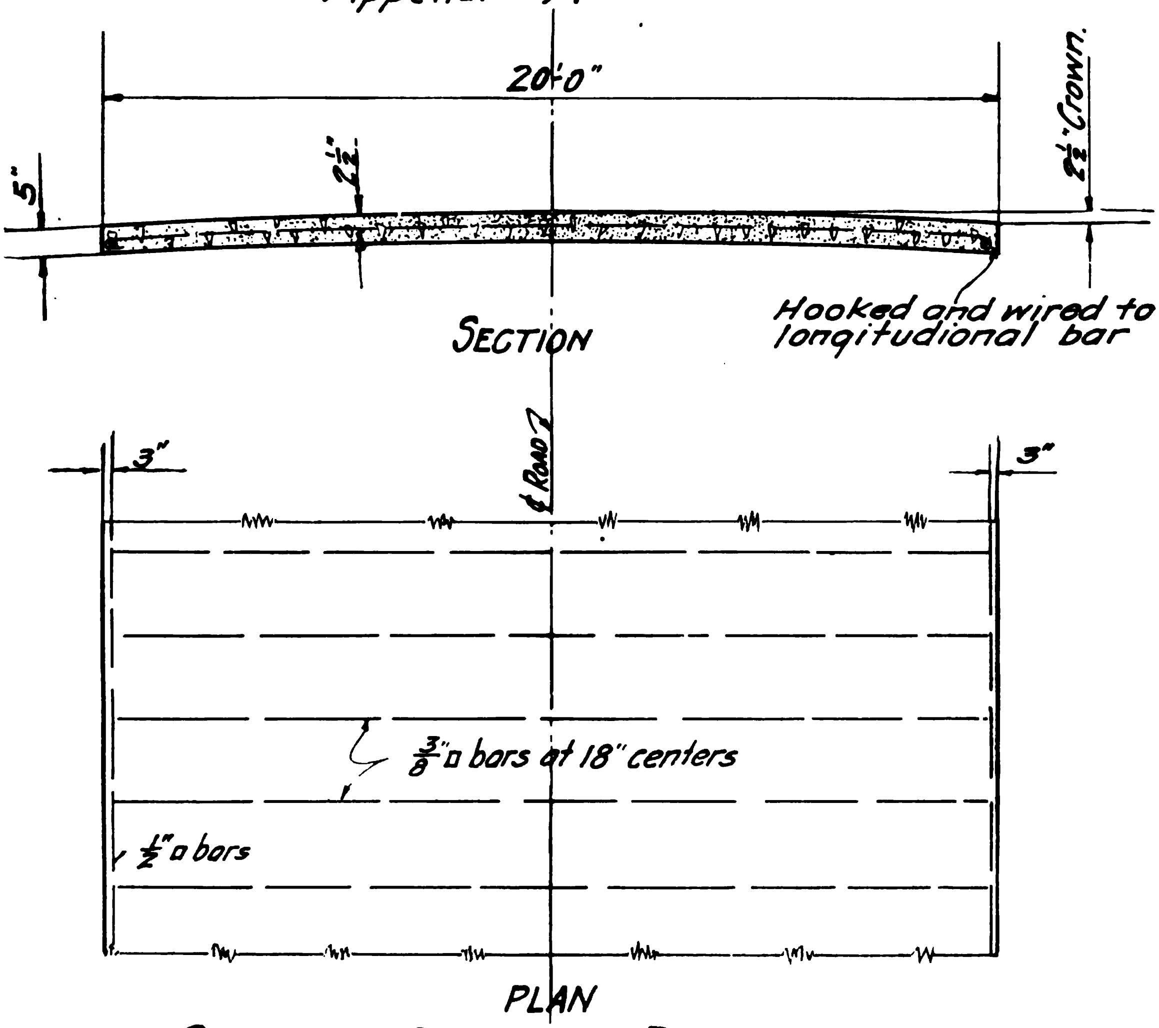


CONCRETE PAVEMENT REINFORCING
VENTURA COUNTY - CALIFORNIA

DATA

Transverse bars placed after the concrete was struck off. A special templet was used to cut a line into the surface of the concrete and the bar was laid in this cut line. Longitudinal bars were placed as the concrete was being poured and were not wired to the cross bars.

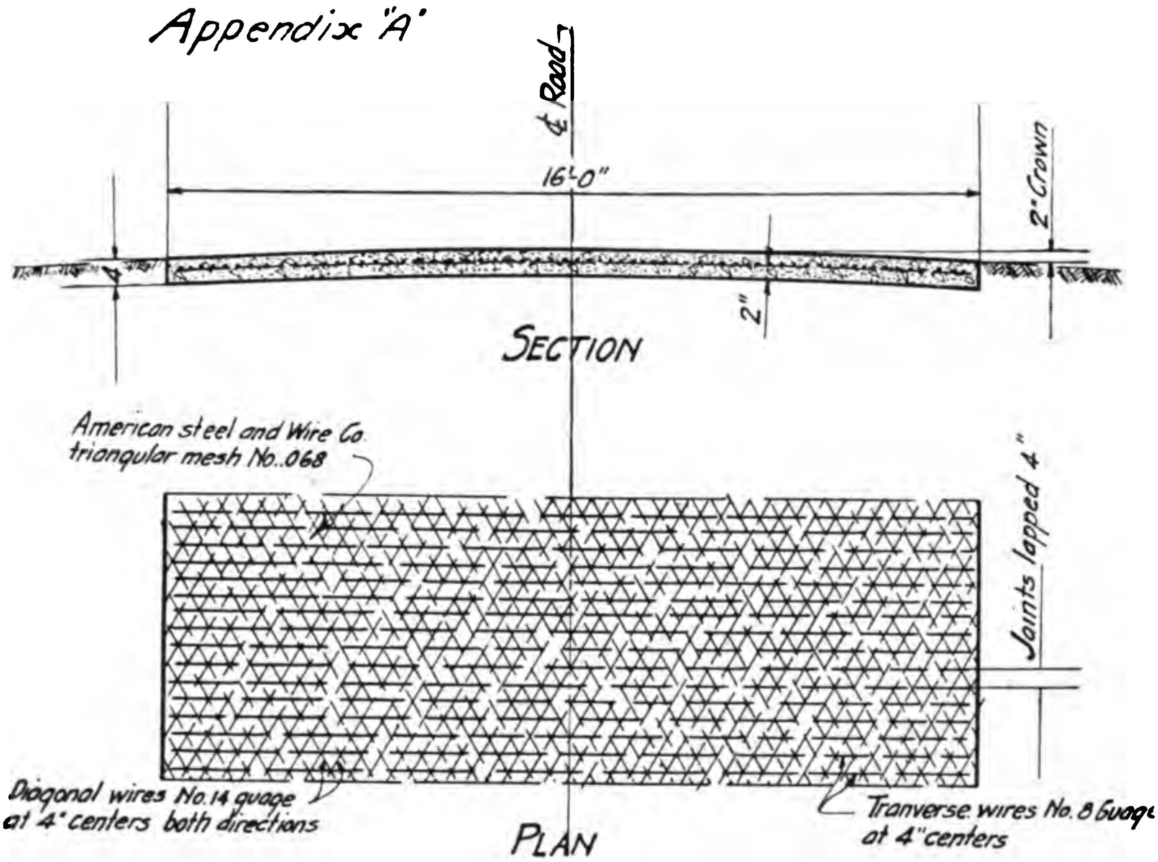
Appendix "A"



CONCRETE PAVEMENT REINFORCING
STATE HIGHWAY

DATA

Longitudinal bars placed with alternate butt and lap joints of one foot. Butt joints on each side pavement are opposite each other. Transverse rods were placed by laying on top of sections of 2-inch pipe which were fastened to the mixer and moved along as the mixer moved. Weight of steel per 100 square feet of pavement—40.3 lbs.



CONCRETE PAVEMENT REINFORCEMENT
SANTA BARBARA COUNTY-CALIFORNIA
ON MISSION DRIVE

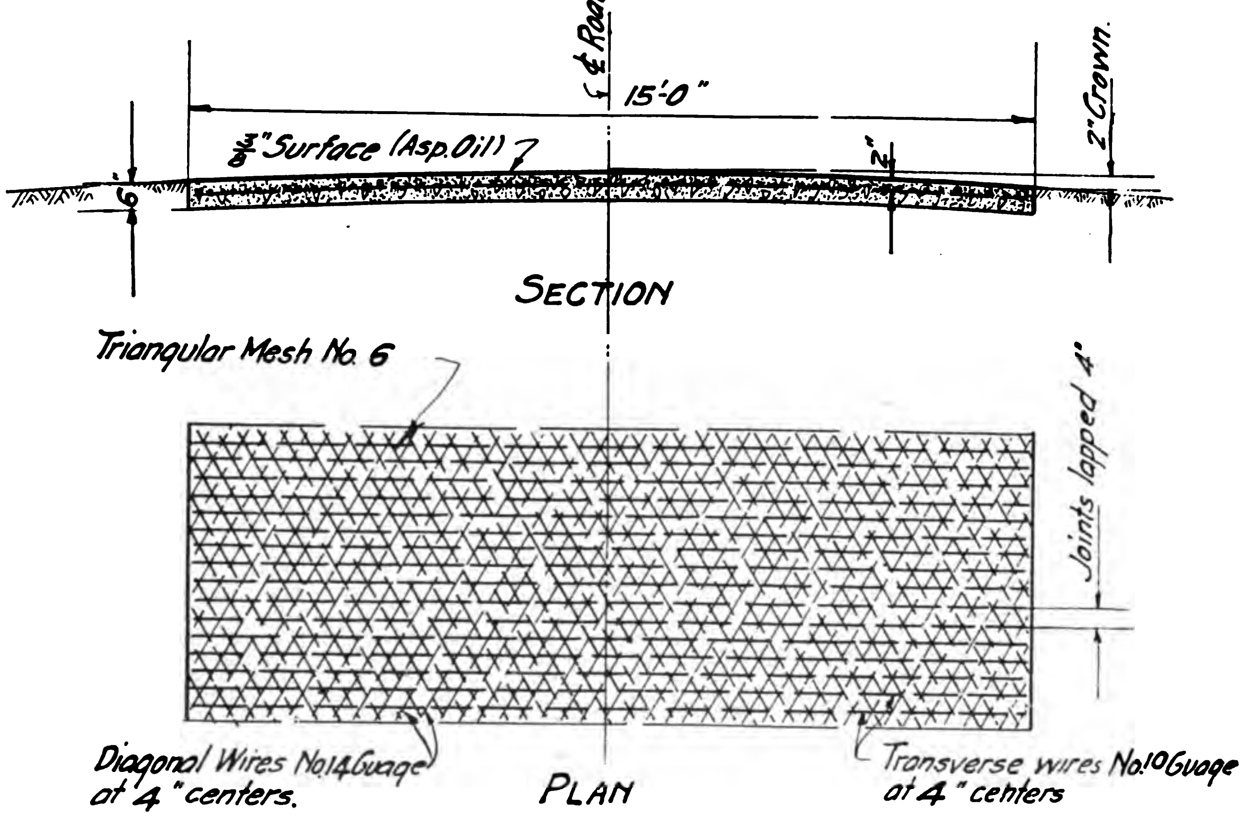
DATA

Type of reinforcing—American Steel and Wire Co. Triangular mesh No. 068.

Weight per 100 square feet of pavement—35 lbs.

Method of placing—laid on the subgrade and drawn up into concrete as same is being poured.

Appendix "A"

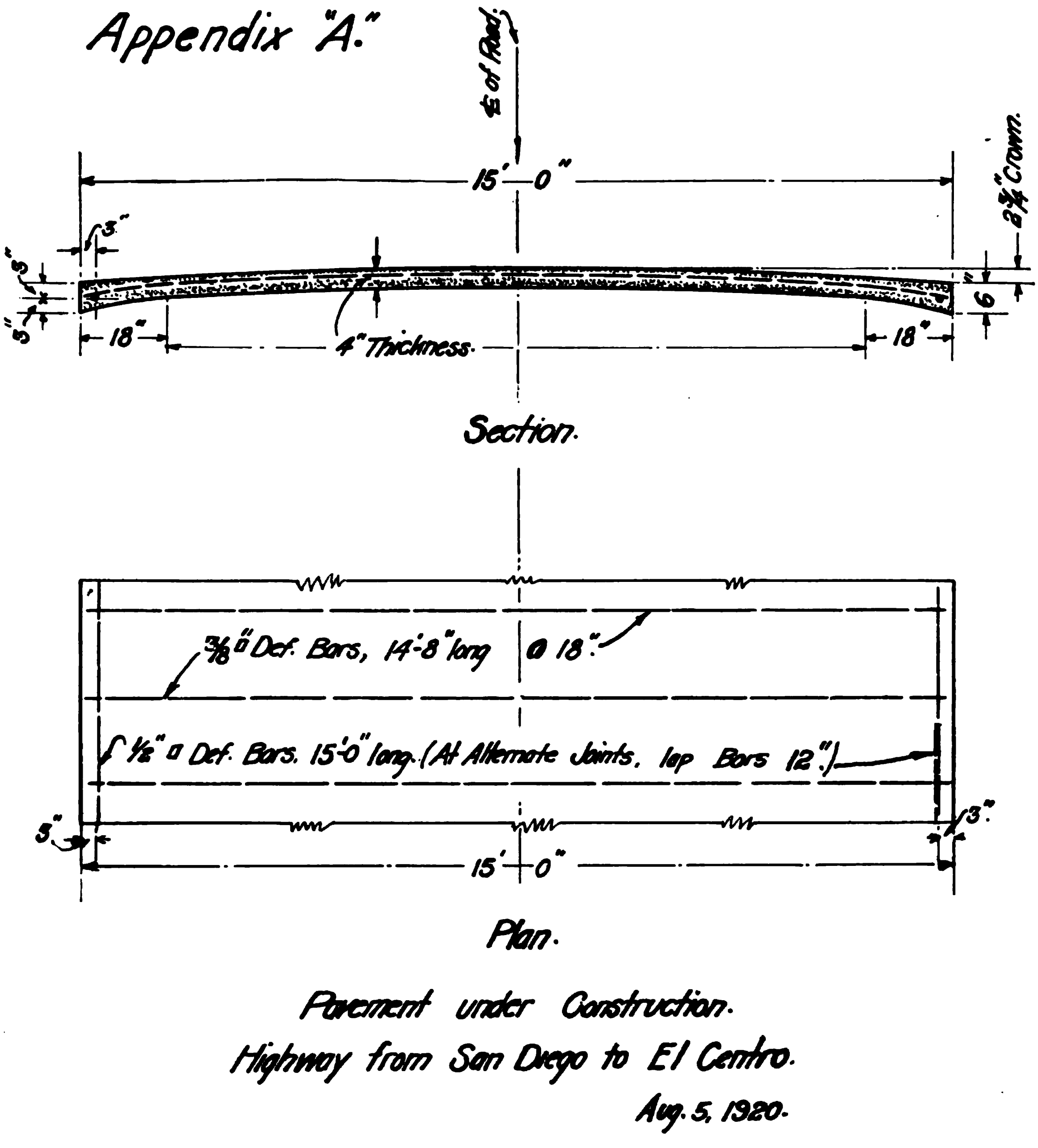


CONCRETE PAVEMENT REINFORCING
STATE HIGHWAY
NEAR NEWBERRY PARK - VENTURA COUNTY

DATA

Reinforcement consists of U. S. Steel Products Company's style No. 6 triangle wire mesh weighing 27 lbs. per one hundred square feet.

Appendix "A."



DATA

Longitudinal bars placed with alternate butt and lap joints of one foot. Butt joints on each side of the pavement are opposite each other. Transverse bars rest on pipe supports during pouring. Longitudinal bars rest in bored holes of templet. Transverse bars hook over and wire to longitudinals. Concrete 1-2-4 mix.

APPENDIX "B"

COLORIMETRIC TEST FOR SANDS

The field test consists of shaking the sand thoroughly in a dilute solution of sodium hydroxide (NaOH) and observing the resultant color after the mixture has been allowed to stand for a few hours. Fill a 12-oz. graduated prescription bottle to the 4½-oz. mark with the sand to be tested. Add a 3 per cent solution of sodium hydroxide until the volume of the sand and solution, after shaking, amounts to 7 oz. Shake thoroughly and let stand for 24 hours. Observe the color of the clear liquid above the sand. A good idea of the quality of the sand can be formed earlier than 24 hours, although this period is believed to give best results.

If the solution resulting from this treatment is colorless, or has a light yellowish color, the sand may be considered satisfactory in so far as organic impurities are concerned. On the other hand, if a dark-colored solution is produced, the sand should not be used in high-grade work such as is required in roads and pavements, or in building construction.

APPENDIX "C"

Stresses in Concrete Paving Slabs Under Different Conditions of Loading and Subgrade.

Case No. 1. Slab Action on Compressible Subgrade.

Using the formula developed by Mr. Goldbeck. (Public Roads, Vol. 1, No. 12, page 37.)

$$S = \frac{P}{2\pi d^2} = \frac{(3R-2r)}{R}$$

where s = maximum fibre stress

P = total wheel load—10,000 #

d = thickness of slab

R = radius of supporting cone of the subgrade = 36″

r = radius of area of contact of load P on surface of the pavement = 5″

Substituting for the fixed quantities we have $S = \frac{4350}{d^2}$

By substitution in this formula for 4″, 6″, 8″ and 10″ slabs, we get the following:

Slab thickness d in.	Tensile stress S-pounds per square inch static load	100% impact 2S pounds per square inch	S′ = S(1–q)			
					25% reduction with constraint	
			Static	Impact	Static	Impact
4	272	544	215	435	161	326
6	121	242	97	194	73	146
8	68	136	54	108	40	80
10	44	88	35	70	26	52

Here q = Poisson's ratio assumed = 0.2 for concrete

This table shows that for 100% impact a 6″ slab gives S′ 194 pounds per square inch, assuming the slab freely supported, and 146 pounds per square inch if 25% constraint is assumed.

The assumptions made for R = 36″ on a fair subgrade show that 4″ slabs are not justified; 6″ slabs should be the minimum thickness on soil of any question.

Case No. 2. Slab Action Over a Depression in the Subgrade.

Assume a wheel load P uniformly distributed on the concrete surface in a circle of diameter

2r and that the concrete pavement of depth d spans a circular depression of diameter 2R and that the slab is freely supported on this circumference. By the analysis already referenced:

$$M = pr^2\,(R-2r/3)$$
$$P = p\pi r^2$$
$$M = \frac{P}{\pi}\,(r-2r/3)$$
$$S = \frac{P}{\pi}\,\frac{(3-2r/R)}{d^2} = \frac{10000(3-10/36)}{\pi\,d^2} = \frac{8300}{d^2}$$

It is seen that this result gives stresses double those of Case No. 1 for slab action on a compressible subsoil.

Since these depressions under a slab are possible with adobe subgrades and the character of building we have thus far had, it is clear that 4″ concrete pavements cannot withstand stresses produced by such a subgrade settlement as is here assumed. Even 6″ slabs must be reinforced. The real cure is to prevent the settlement of the subgrade if possible. Calculations are not carried further in this case because the worst tendencies for the cracking of pavements do not come from Cases 1 and 2, but rather from plain beam or plain slab action as in the two cases yet to be cited.

The above formula for S is static load of 10,000 lbs. on a 10″ wheel-base; with impact the stresses must be higher.

Case No. 3. Diagonal or Corner Cracks.

Cantilever beam action at the corner of a paving slab unsupported by the subgrade.

Using Mr. Goldbeck's analysis $S=\frac{3P}{d^2}$ where

S=unit tensile, stress in the concrete.

P=total load, assumed to be 10,000 lbs.

d=thickness of the slab.

Substituting in this formula for 4″, 6″, 8″, 10″ and 12″ slabs, we get the following values of S for a load of 10,000 lbs.:

d=4	s=1,875 lbs.
d=6	s= 833 "
d=8	s= 469 "
d=10	s= 300 "
d=12	s= 208 "
d=14	s= 153 "

Case No. 4. Cantilever Beam Action at the Edge of the Pavement Slab Unsupported by the Subgrade.

Assume a lateral unsupported cantilever of length 1—36″ measured from the side of the pavement toward the center. P=10,000 lbs. Assume that the width of the cantilever is 72 inches. This assumption is arbitrary but it is probably larger than actually occurs in slabs. $P=\frac{10{,}000}{72}=139$ lbs. per longitudinal inch of slab or for a cantilever beam of 1 inch width. Adding 100% for impact the unit load becomes 278 lbs. For the unit stress in the concrete we therefore have

$$M = PL = 278 \times 36 = 10{,}000''\# = \frac{Sd^2}{6}$$
$$S = \frac{6PL}{d^2} = \frac{6M}{d^2}$$

For 4″ slab $S = \frac{60{,}000}{16} = 3750$ pounds per square inch

Since concrete in tension cannot stand more than about 1/10 this value, it is obvious that a 4″ slab is wholly inadequate.

Stresses in slabs of different thickness under the same condition of loading and support would be as follows:

With a 6″	slab,	S =	1,660
8″	"	S =	940
10″	"	S =	600
12″	"	S =	418
14″	"	S =	305
16″	"	S =	235
18″	"	S =	185
20″	"	S =	150

It is seen then that with 100% impact and a 3-foot cantilever overhang, a plain concrete slab must be 18″ to 20″ thick.

Under the same condition of loading and support we have the following calculation for the amount of reinforcement necessary in a 6-inch concrete slab.

Assume the steel bars 1.5″ from the top of pavement. The effective depth d then is 4.5″; the moment lever arm jd=.87x4.5=3.9″; compression depth in concrete above neutral surface kd=0.4x4.5=1.8″.

As before M=P1=278x36=10,000″ lbs.

The total fiber stress $F_s = \frac{M}{jd} = \frac{10,000}{3.9} = 2560$ lbs.

Assuming the working stress in the steel bars $f_s = 20000$ pounds per square inch,

$A_s = \frac{2560}{20000} = 0.128$ square inches.

Thus there would be required running transversely across the pavement ½″ square bars at 2″ centers.

The maximum compression stress in the concrete at the bottom of the slab is:

$$fc = \frac{2F}{kd} = 2 \times \frac{2560}{1.8} = 2850 \text{ pounds per square inch.}$$

Note therefore that the compression stress in the concrete approaches and is practically equal to the ultimate crushing strength of the very best concrete.

If the steel is 1″ from the top surface of the pavement, d = 5″, jd = 4.35″, kd = 2″, F = 2300 #, $A_s = 0.115$ equivalent to ½″ square bars at 2.2″ centers and $f_c = 2300$ pounds per square inch.

For an 8″ slab with steel 1½″ from the top, d = 6.5″, jd = 5.65″, kd = 2.6″, F = 1770 #, $A_s = 0.088$ equivalent to ½″ square bars at 2.85″ spacing, and $f_c = 1360$ pounds per square inch.

SUMMARY OF SLAB TESTS

...sured on fractured Section ... may be used to calculate ...ths and spans, but not for these values computed from

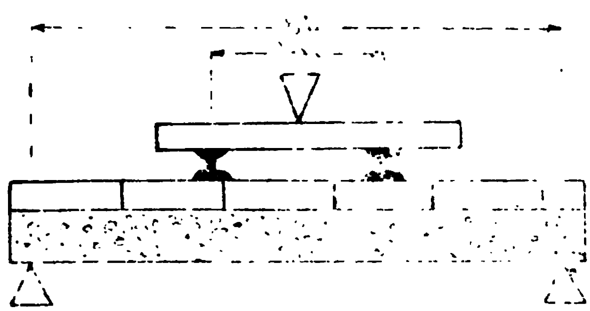
Brick Specimens marked "B"
" " "B.P."
...cement " " "C"
...se " " "C.B."

Base for all Brick Specimens Mixed dry in mixe... and ... with 30" ... Struck with ... and ... on ... Base ... Except B1, B2, ...

Concrete Specimens Mixed as above Spaded into forms and rolled three times at intervals of 30 minutes then struck off with templates except 5 0-1 & 6 a-2 which were tamped instead of rolled.

*Depth given in

** Values in this co... load for differen... different depths a 24" span



NOTE: Monolithic Standard Concrete

All beams broke thus

Speed used ... to one minute

Appendix "E"

1920 Concrete Pavements, State Highway Awards

State	Width, Feet	Thickness, Inches	Proportions
California	15-20	4-6	1:2:4
Colorado	18	6-7½	1:2:3
Connecticut	16-20	6-8	1:2:4
Delaware	14-18	5-7 & 6-8	1:2:4-1/10 Hyd. Lime
Georgia	16-18	6 uniform	1:2:4
Idaho	18	5½-6½	1:2:3
Illinois	16-20	8 uniform	1:2:3½
Indiana	18	6-8	1:1½:3
Iowa	18	7-8	1:2:3½
Kansas	18	6-8L	1:2:3½
Maine	16	6-8 & 7-8 reinf.	1:2:3½
Maryland	15-18	5-7 & 6-8	1:1½:3
Massachusetts	18	5-7¼	1:2:4:8/100 Hyd. Lime
Michigan	16-20	6-8	1:1½:3
Minnesota		7-8	1:2:3½
Mississippi	9-18	6 uniform	1:2:3
Missouri	18	6-8 & 7-9	1:2:3
Nevada	9-16	6 uniform	1:2:4
New Jersey	18-20	6-8 to 10-12.5	1:2:3
New Mexico	16	5-7	1:2:3
New York	16-20	5-6 & 6-8 reinf.	1:2:4
North Carolina	18	7 uniform	1:1½:3
Ohio	10-20	6-8 & 8-10	1:1½:3
Oklahoma	18	7 uniform	1:2:3
Oregon	18	6-7	1:1½:3
Pennsylvania	16-18	5-7 & 6-8	1:2:3
Rhode Island	18	6-8	1:2:3
South Carolina	16-18	6	1:2:4
Tennessee	16-18	6-8	1:2:4
Texas	15-18	6-8 uniform	1:2:3½
Utah	18	6-8	1:1¾:3½
Virginia	16-18	6-8	1:2:4
Washington	18-20	6-7½	1:2:3
West Virginia	16	6-8	1:2:3
Wisconsin	18	7-8	1:2:3½

Appendix "F"

a. Destruction of cement mortars and concrete through expansion and contraction. (A. H. White, Engineering Record, 64, 45, July 8, 1911.)

b. The expansion and contraction of concrete while hardening. (A. T. Goldbeck, Engineering Record 64, 73, July 15, 1911.)

c. Shrinkage of concrete and conditions of curing. (F. R. McMillan, Engineering Record, April 17, 1915.)

d. The expansion and contraction of concrete roads. (Goldbeck & Jackson, page 27, Bulletin No. 532 U. S. Dept. of Agriculture.)

e. Test of the Sears-Roebuck Building, by D. E. Hooker. (Pacific Northwest Society of Engineers, Proceeding XV, 88-90, January, 1916.)

f. Shrinkage and Time Effects in Reinforced Concrete, by F. R. McMillan. (Bulletin No. 3, University of Minnesota, March, 1915.)

g. Concrete Roads, W. A. McIntyre. (The Cornell Civil Engineer, 24, 331, April, 1916.)

h. In Engineering News-Record 83, 518-520, September 11, 1919, under the heading, "Does Rich Concrete in Roads Crack More Than Lean?" are answers to a questionnaire by: E. N. Hines, A. N. Johnson, Clifford Older, P. St. James Wilson, Duff Abrams, A. H. Hinkle, J. C. Pearson and W. D. Uhler.

THE REPORT OF THE COMMITTEE ON MODIFICATION OF LAWS RELATIVE TO WEIGHT AND SPEED OF VEHICLES

DAVID R. FARIES, General Counsel of the Automobile Club of Southern California, Chairman.
WATT MORELAND, General Manager, Moreland Motor Truck Company.
C. H. RICHARDS, Engineer.

The results obtained from the engineering investigations conducted by the Automobile Club of Southern California demonstrate that California's present highways are not capable of withstanding the effects of the present traffic over them and that they will not be able to resist the effects of future traffic. The committee on the modification of laws relative to weight and speed of vehicles believes that all future highways constructed in California should be constructed in such a manner as to warrant the hope that they will survive the effects of not only present day traffic but of the greatly increased volume of traffic which will undoubtedly make use of our highways in the years to come.

While we believe that the alarming disintegration of our present highways is due in the main to the manner of their construction, it is nevertheless true that the overloading and overspeeding of motor vehicles is seriously injuring the 1,400 miles of state pavements already built which must be used as they are.

The abusers of the highway are chiefly responsible for the criticisms being leveled at all highway users. California has a vehicle act intended to regulate traffic on its highways both as to speed and as to weight. The speed provisions have, as to private passenger cars, been fairly well enforced, by the officers of the law; these same officers, however, have made little, if any, effort to enforce the provisions defining and prohibiting the overloading of vehicles. This lack of enforcement has caused many truck operators to remain in the grossest ignorance of the law while others have flagrantly violated its provisions. The census of traffic on our state highways as given previously in this report contains data amply supporting these assertions.

Public-spirited, law-abiding truck operators will, however, be found in great numbers ready to aid in the careful enforcement of the laws regulating the weight and speed of their vehicles, as they realize that these laws have been carefully drawn and that the legal operation of their trucks is the efficient, economical and profitable method of operation.

Overloading is not only a violation of the laws of the state but is also, in most cases, contrary to the wishes and recommendations of truck manufacturers. Manufacturers and dealers, realizing that overloading shortens the life of the vehicle they manufacture or sell and thereby brings it into undeserved ill repute, and realizing that public sentiment will not long endure an abuse of the highways constructed at public expense, are urging rational loading and the restriction of speed on the part of truck operators.

This committee believes that restrictions imposed by law as to the size and width of vehicles, the maximum loads to be carried therein, the relationship between the maximum load of vehicle and contents and width of tire and the relationship between weight and speed are engineering problems. We believe that the legislature should simply put into the Vehicle Act the engineering conclusions to be deduced from the investigations conducted by the Automobile Club of Southern California and the California State Automobile Association. We also believe that once this is done the law should be rigidly enforced with a view to preserving our highways as long as possible and in as good condition as possible. We believe that the California Vehicle Act as it now stands is an excellent piece of legislation, but should be modified in certain particulars. The modifications, we suggest, are as follows:

Maximum Weight

The present Vehicle Act provides for a maximum weight of vehicle and load of 30,000 lbs. It is the opinion of the engineers for the Automobile Club of Southern California, in which this committee concurs, that this maximum should be lowered to 28,000 lbs.

From the schedule of state laws attached to this report, it will be seen that of the states having vehicle load restrictions, none permit loads exceeding California's gross load of 30,000 lbs. with the possible exception of Ohio, which has a limit of 800 lbs. per inch of tread, and Indiana, with a capacity of load of 20,000 lbs. exclusive of truck weight.

Weight on One Axle or Wheel

The weighing in connection with this investigation by engineers of the Automobile Club of Southern California of a number of trucks as disclosed in the truck census contained in this report, shows that about 75 per cent of the load of a truck is carried on its rear wheels. This practical demonstration corresponds with the theory of manufacturers of trucks on the subject.

It is the recommendation of the Club's engineers that the maximum weight to be allowed by law to rest upon any one wheel of a vehicle be not more than 10,000 lbs. This recommendation is joined in by the members of this committee with the exception of Mr. Moreland, who advocates that a gross weight of 11,200 lbs. be allowed on any one wheel or 22,400 lbs. on any one axle. This recommendation of Mr. Moreland conforms to the recommendations of the proposed Uniform Vehicle Act adopted by the joint committee on uniform vehicle laws which issued a pamphlet dated January 20, 1920, containing a proposed uniform vehicle law. This joint committee was composed of representatives of the American Association of State Highway Officials, the National Automobile Chamber of Commerce, the American Automobile Association and the Federal Highway Council.

The majority of the committee believe that Mr. Moreland's recommendation might prove very desirable in states where the highways constructed are sufficiently strong to resist such weights. It is the opinion, however, of the engineers of the Automobile Club of Southern California that California's highways cannot resist the wear of loads in excess of 10,000 lbs. on any one wheel. The majority of the committee admit that such a restriction may prevent the use of 7½-ton trucks when loaded to full capacity, but believe that such a limitation is made necessary by the highway conditions in this State. The majority of the committee also call particular attention to the weight restrictions contained in the table annexed to this committee's report and direct attention to the fact that Illinois and Iowa limit the gross weight on one wheel to 8,000 lbs. notwithstanding the fact that these states have eight-inch concrete pavements on their main roads.

Weight on Tires

The present California Vehicle Act provides that the load of a vehicle shall not exceed 800 lbs. per inch per width of tire when solid rubber tires are used. The engineers of the Automobile Club of Southern California and this committee believe that this restriction should be kept in the law but re-written so as to be made to definitely express the intentions of the framers of the law. The law should be made to definitely state that a limitation of load includes the weight of both vehicle and load. The width of the tire should be measured at the base of the tire rather than at the point of contact with the highway. The reason for this statement is that solid rubber tires as usually manufactured and sold are, when new, narrower at the point of contact with the highway than at the base. A new tire is much more desirable because of its thickness and resiliency than a tire which has been worn down by long use, but a law which requires measurement of the tire at the point of its contact with the highway penalizes the use of new tires and discriminates in favor of the tire which is practically worn out. The effect on the road of old worn tires is shown on page 120.

A glance at this table will show that the speed of 14.6 miles per hour, with a drop of two inches, in the case of a three-ton truck with a $4\frac{1}{2}$-ton load produces an impact with an old worn solid tire of 26,500 lbs. as compared with 18,700 lbs. with a new solid tire and 8,300 lbs. with a pneumatic tire.

The effect of this impact on the truck is, of course, in proportion to that on the highway, so whether we are trying to protect the truck or the highway or both, we should favor a statute requiring the measurement of the tire at its base at the rim rather than at the point of contact with the road.

Permit for Excessive Size and Weight

This committee recommends that the present provisions of the Vehicle Act authorizing the granting of permits by the Highway Commission for the transportation over the highways of vehicles of excessive size or weight be further restricted as to prevent the granting of such permits, unless the vehicle whose use is thus permitted is equipped with at least one inch of tire width for every 800 lbs. of the weight of such vehicle and its load.

Thickness of Rubber on Solid Tires

This committee also favors the inclusion in the law of a provision prohibiting the use of any solid tire which is, on account of excessive use or for any other reason, less than one inch thick where its width is five inches or more and prohibiting the use of new tires less than three-quarters of an inch thick where the tire is less than five inches wide.

Cushion Wheels

The type of wheel known as the cushion wheel is now in use, which has not been taken into consideration in the preparation of vehicle laws. Users of these wheels claim that the vibration of a truck equipped with them is much less than that of one equipped with solid tires. The proponents of this type of wheel ask that it be considered in the law and this committee represents that while no favor be shown this type of wheel over the solid tire as to size or weight restrictions, that the speed limits imposed upon solid tired vehicles be modified in favor of cushion wheel vehicles so as to permit them to travel at a rate of speed 25 per cent in excess of the speed limits imposed upon solid tired vehicles of the same weight and load capacity, provided that such increases in speed shall in no case permit the cushion wheel vehicle to exceed the speed limit fixed for pneumatic tired vehicles.

Speed of Freight Vehicles

This committee is advised by the engineers for the Club that tests show that vehicles equipped with pneumatic tires do a great deal less damage to the roads than vehicles equipped with solid tires. We are also advised that the damage done by a vehicle to the highway is caused not by the weight of the vehicle alone, but by a combination of the weight and of the speed. We are told that the force of impact of a solid tired vehicle increases approximately with the square of its speed—that is, that a solid tired vehicle traveling at twenty miles per hour produces four times as great an impact on the highway as the same vehicle traveling at ten miles per hour, and nine times as much impact when traveling at thirty miles per hour as when traveling at ten miles per hour. Granting this, it will readily be agreed that there must be definite speed limits on heavy vehicles considerably slower than those allowed the ordinary passenger vehicle. In considering the recommendations it should make on this subject, this committee has carefully considered the speed laws of every State in the United States and various proposed uniform vehicle acts including the one already referred to herein which was prepared by the joint committee on uniform vehicle laws, the International Traffic Officers' Association and other organizations. We have also had the

benefit of engineering data prepared by the engineers of the Automobile Club of Southern California and others. We recommend that in addition to the provisions of the State law requiring that all vehicles be operated in a careful and prudent manner and at a rate of speed not greater than is reasonable and proper, having due regard to the traffic, surface and width of the highway, that the operators of vehicles intended, defined or used for the transportation of property and equipped with pneumatic tires be required to operate such vehicles at rates of speed not exceeding twenty-five miles per hour in open country, twenty miles per hour in resident districts and fifteen miles per hour in business districts. We further recommend that, subject to the same restrictions, the operators of vehicles equipped with solid tires shall be prohibited from exceeding a speed set forth in the following table:

Vehicle and Load Weighing	Open Country M.P.H.	Residence M.P.H.	Business M.P.H.
Less than 4,000 lbs.	22	18	14
4,000 lbs. or more but less than 6,000 lbs.	20	16	12
6,000 " " " " " " 8,000 "	18	14	12
8,000 " " " " " " 12,000 "	16	12	10
12,000 " " " " " " 16,000 "	14	10	8
16,000 " " " " " " 20,000 "	12	10	8
20,000 " " " " " " 24,000 "	10	8	6
24,000 " " " " " " 28,000 "	10	8	6

Load Plates

In order that restrictions as to weight and speed may be subject to practical enforcement, we recommend that all applications for licensing of vehicles state the manufacturer's rating of the load capacity and the size of the tires to be used. The changing of the size of the tire to a size exceeding that stated in the application should be prohibited. Having this information the Vehicle Department should be required to issue with the license for every freight-carrying vehicle a load plate which the license should be required to affix to the outside of the vehicle. This plate should state the license number and engine number of the vehicle and the maximum load and speeds permitted to it.

Fees and Fines

This committee believes that the fees collected by the State from licensing of motor vehicles should not be based upon horse-power alone as at the present time, but that such fees should be based both on horse-power and weight. We suggest the following table as a substitute for the present schedule of fees:

Vehicles Equipped With	Per Horse-power or Major Fraction Thereof	And Per 100 Lbs. of Gross Weight of Vehicle and Load
Pneumatic Tires	25c	25c
Solid tires of rubber or other elastic material	25c	35c
Solid tires of metal or other hard material	25c	50c

This committee further recommends that all fees, fines and forfeitures collected anywhere in the State be paid into and become a part of the Motor Vehicle Fund.

Trailers

This committee is informed of a movement to eliminate the present restrictions of the law prohibiting the operation of more than two trailers with any one towing vehicle. We are opposed to the elimination of this provision, believing that it would be detrimental to the highways and dangerous to traffic.

Uniformity of Legislation Desirable

Much vehicular traffic is interstate in character. Most vehicles travel frequently from one county to another. The situation imperatively demands uniform motor vehicle laws. It is unreasonable to expect manufacturers to build their equipment to meet an endless variety of different State and county requirements. Every effort should be made to harmonize these requirements and to secure the adoption of uniform laws. A National Conference on Highway Traffic Regulation has been formed which includes in its membership practically all the large responsible organizations interested for any reason in the regulation of traffic. This conference will meet January 10, 1921, in Washington, D. C., and it is to be hoped will be productive of much good. We recommend that every effort consistent with the preservation of our local highways be made to conform to the California law and to any uniform law which may be agreed upon by the conference.

Respectfully submitted,

DAVID R. FARIES,
General Counsel of the Automobile Club of Southern California.

WATT MORELAND,
General Manager, Moreland Motor Truck Co.

C. H. RICHARDS,
Engineer.

Showing breaking up of pavement at expansion joint.

Detail of breaking up of concrete.

Table No. 1

SIZE AND WEIGHT RESTRICTIONS IN STATE MOTOR VEHICLE LAWS EFFECTIVE

JULY 1, 1920

(Compiled by the Legal Department of the Automobile Club of Southern California.)

In the weight restrictions column the per inch width of tire limits fixed by the States of Illinois, Iowa, Kentucky and Vermont are based upon the measurement of the contact of the tire with the road; in the case of Ohio and Virginia the distance between the flanges of the rim is the basis of measurement; in the other instances no specific basis other than "per inch of tire width" is prescribed.

State	Weight Restrictions	
California	30,000 lbs.	gross weight—800 lbs. per inch of tire width
Connecticut	25,000 lbs.	gross weight distributed not more than 700 lbs. per inch of tire width
Delaware	26,000 lbs.	gross weight distributed not more than 700 lbs. per inch of tire width
Illinois	16,000 lbs.	gross weight limit for one axle distributed not more than 800 lbs. per inch width of tire
Indiana	20,000 lbs.	capacity
Iowa	28,000 lbs.	gross weight for vehicle and load;
	8,000 lbs.	for any one wheel distributed not more than 800 lbs. per inch width of tire
Kentucky	30,000 lbs.	gross weight distributed not more than 800 lbs. per inch width of tire for non-metal tires
Maine	18,000 lbs.	distributed not more than 800 lbs. per inch width of tire
Maryland	20,000 lbs.	gross weight distributed not more than 650 lbs. per inch width of tire
Massachusetts	28,000 lbs.	gross weight distributed not more than 800 lbs. per inch width of tire
Michigan	700 lbs.	maximum load for tire 2 in. wide up to 3,200 lbs. for 7-in. tire on wheel of 32 in. in diameter
New Jersey	30,000 lbs.	gross weight distributed not more than 800 lbs. per inch width of tire
New Mexico		Rim or tire must be 3 inches or more wide if intended carrying capacity exceeds 2,000 lbs.
New York	25,000 lbs.	gross weight distributed not more than 800 lbs. per inch width of tire (outside of cities)
North Carolina	11,000 lbs.	capacity
Ohio		Tires of rubber or other similar substances 800 lbs. per inch of width on all tires
Oregon	10,000 lbs.	carrying capacity 600 lbs. per inch width of tire
Pennsylvania	26,000 lbs.	gross weight distributed not more than 19,500 lbs. on one axle nor more than 800 lbs. per inch of tire width
Rhode Island		Without special permit gross weight of trailer limited to 4,000 lbs.
South Carolina	8,000 lbs.	capacity
Texas	5,000 lbs.	gross weight per wheel distributed not more than 500 lbs. per inch width of tire

State	Weight Restrictions
Utah	20,000 lbs. gross weight
Vermont	12,500 lbs. in towns or incorporated villages, other places 10,000 lbs. gross weight distributed not more than 600 lbs. per inch of tire width
Virginia	24,000 lbs. gross weight distributed not more than 700 lbs. per inch of tire width for solid tired vehicles
Washington	10,000 lbs. for load outside of cities of first or second class
West Virginia	30,000 lbs. gross weight distributed not more than 600 lbs. per inch of tire width
Wisconsin	24,000 lbs. gross weight distributed not more than 18,000 lbs. per axle nor more than 800 lbs. per inch of tire width
District of Columbia	12,000 lbs. gross weight on bridges with wooden floors; 30,000 on any other bridges

States having no laws dealing with the subject are as follows:

Alabama, Arizona, Arkansas, Colorado, Florida, Georgia, Idaho, Kansas, Louisiana, Minnesota, Mississippi, Missouri, Montana, Nebraska, Nevada, New Hampshire, North Dakota, Oklahoma, South Dakota, Tennessee and Wyoming.

States in which special permits may be issued for other loadings are:

California, Connecticut, Delaware, Illinois, Maine, Maryland, Massachusetts, New Jersey, Oregon, Pennsylvania, Rhode Island, South Carolina, Texas, Vermont, Washington, West Virginia, Wisconsin and the District of Columbia.

States in which the number of trailers are specified are as follows:

California	Two
Michigan	Two
New Jersey	One
Pennsylvania	One
Vermont	One
District of Columbia	One

BIBLIOGRAPHY

No comprehensive bibliography was found relative to American highways. In order to have available for the preparation of this report and also for purposes of general reference for all those interested in construction of roads, it was decided to prepare a complete bibliography. This work was undertaken by Prof. Charles C. Derleth, Jr., Dean of the Engineering School of the University of California, and his assistants. These gentlemen had at their disposal the files of the Engineering Department as well as the University library. They conducted extensive correspondence, particularly to accumulate the periodicals necessary for research for the bibliography. An index has been prepared containing over three thousand cards giving the subject and the reference. The bibliography has been made to extend over standard books, periodicals and government publications. The following general subjects have been discussed:

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11u1	Smoothness	2	
11u2	Temperature	3	
11u3	Types and construction	0	
11v	Tractive effort	14	
11w	Traffic census	19	
11x	Selection of type	15	
11y	Wear of roads	26	874
12. Literature on Highways			
12a	Bulletins	17	
12b	Handbooks	10	
12c	Pamphlets	16	
12d	Publications in book form, not treatises	22	
12e	Treatises	33	98

13. **Concrete**		No. of Cards	Total Cards Per Group
13a	Aggregates	23	
13b	Calcium chloride	3	
13c	Expansion and contraction	5	
13d	Hydrated lime	15	
13e	Oil	5	
13f	Properties as affected by	6	
	13f1 Age of cement	1	
	13f2 Alkali	70	
	13f3 Curing	5	
	13f4 Fineness of cement	1	
	13f5 Mixing	5	
	13f6 Regaging	1	
	13f7 Tannic acid	1	
	13f8 Temperature	2	
	13f9 Vibration, pressure, rodding	2	
13g	Proportioning	16	
13h	Reinforcement	11	
13i	Tests	13	
13j	Treatises on	26	
13k	Water, amount of	13	224
	Total number of cards = 2,619		

These cards have been placed in an index in the office of the Consulting Engineer of the Automobile Club, 1104 Central Building, Los Angeles, for research without charge, to any who are interested in improved highways of the Southwest.

SUMMARY OF THE RESULT OF THE INVESTIGATION OF THE BIBLIOGRAPHY PERTAINING TO THE EFFECT OF ALKALI ON CONCRETE ROADS
BIBLIOGRAPHY ASSEMBLED AND SUMMARIZED BY

PROF. C. DERLETH
Dean of the School of Civil Engineering of the University of California

The reliability of existing information on the disintegration of concrete by alkali is questionable. This statement does not apply to the publications of the Bureau of Standards, Bulletins 12, 44 and 95, which are without question the most important contributions to the literature on this subject. Other investigations have been made but, taken as a whole, the results of investigations and tests are not conclusive. Future study, based on the present information, will no doubt yield important results.

The most important examples of certain failure which have been reported are in Canada. Many of the articles telling of these failures describe only the extent of disintegration and attribute the cause to alkali because of its presence in the surrounding soil. In no case do they give the history of the concrete which may have been made with bank-run gravel (which is rarely of good grading) and sand with high organic content or may have been prepared with an excess of water or under conditions which would yield concrete of low resistance to stress and weathering. In Canadian territory the disintegration may have been hastened by frost action as well.

One important structure which shows disintegration is the Winnipeg aqueduct; see Engineering News-Record, 84, 1097, June 3, 1920. But there are many instances where concrete is satisfactorily withstanding the forces which disintegrate some concrete.

The alarm shown by certain writers does not seem to be justified by the facts. The subject is nevertheless very important and is being investigated by a committee of 12 engineers appointed by the Engineering Institute of Canada and the Portland Cement Association under the direction of Duff Abrams who is planning to conduct experiments in various parts of the United States. An attempt is also being made to interest the Research Council of Canada.

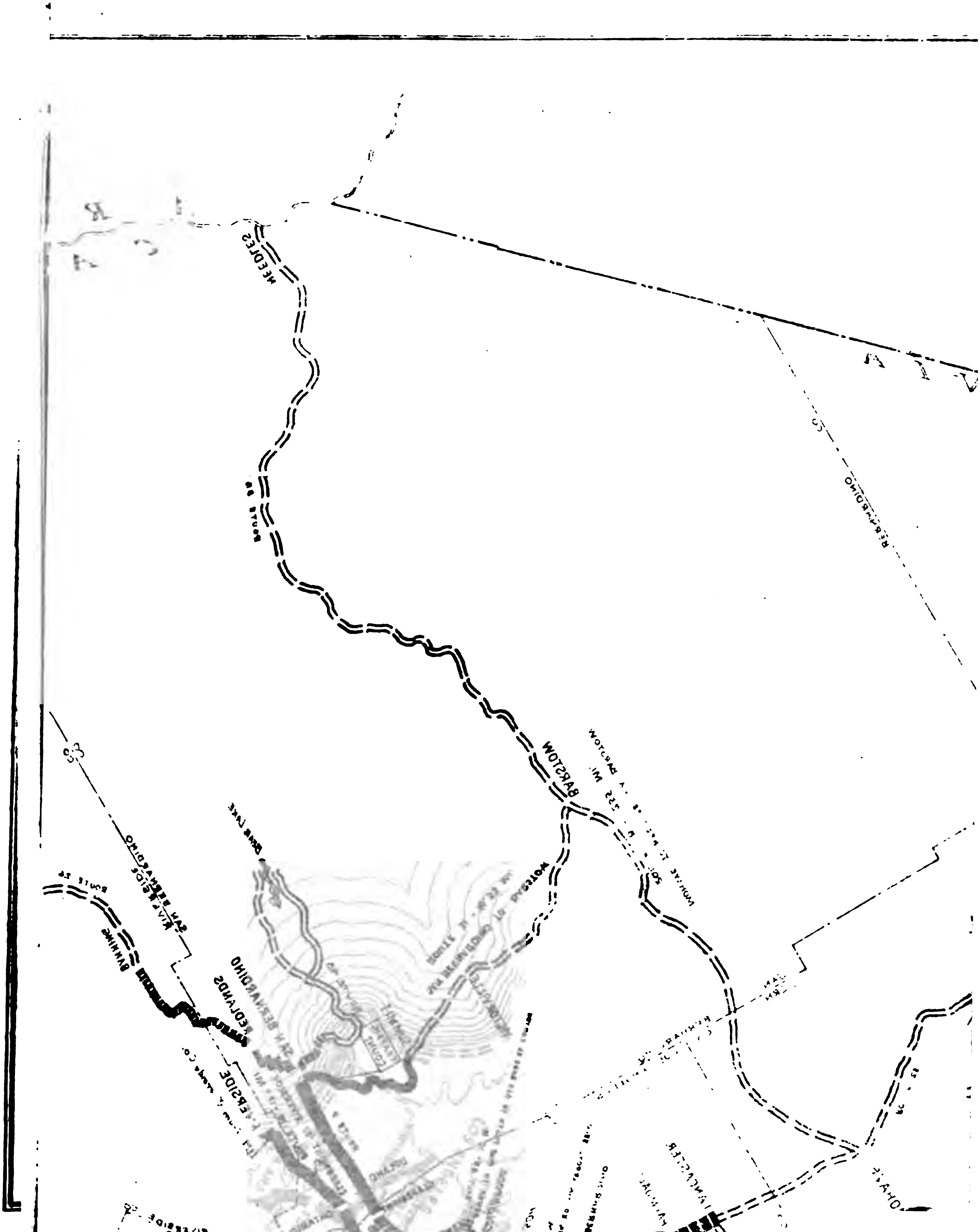
The principal publications which we examined in our search are listed below. The 69 cards attached thoroughly cover the subject of THE EFFECT OF ALKALI ON CONCRETE.

C. DERLETH, JR.

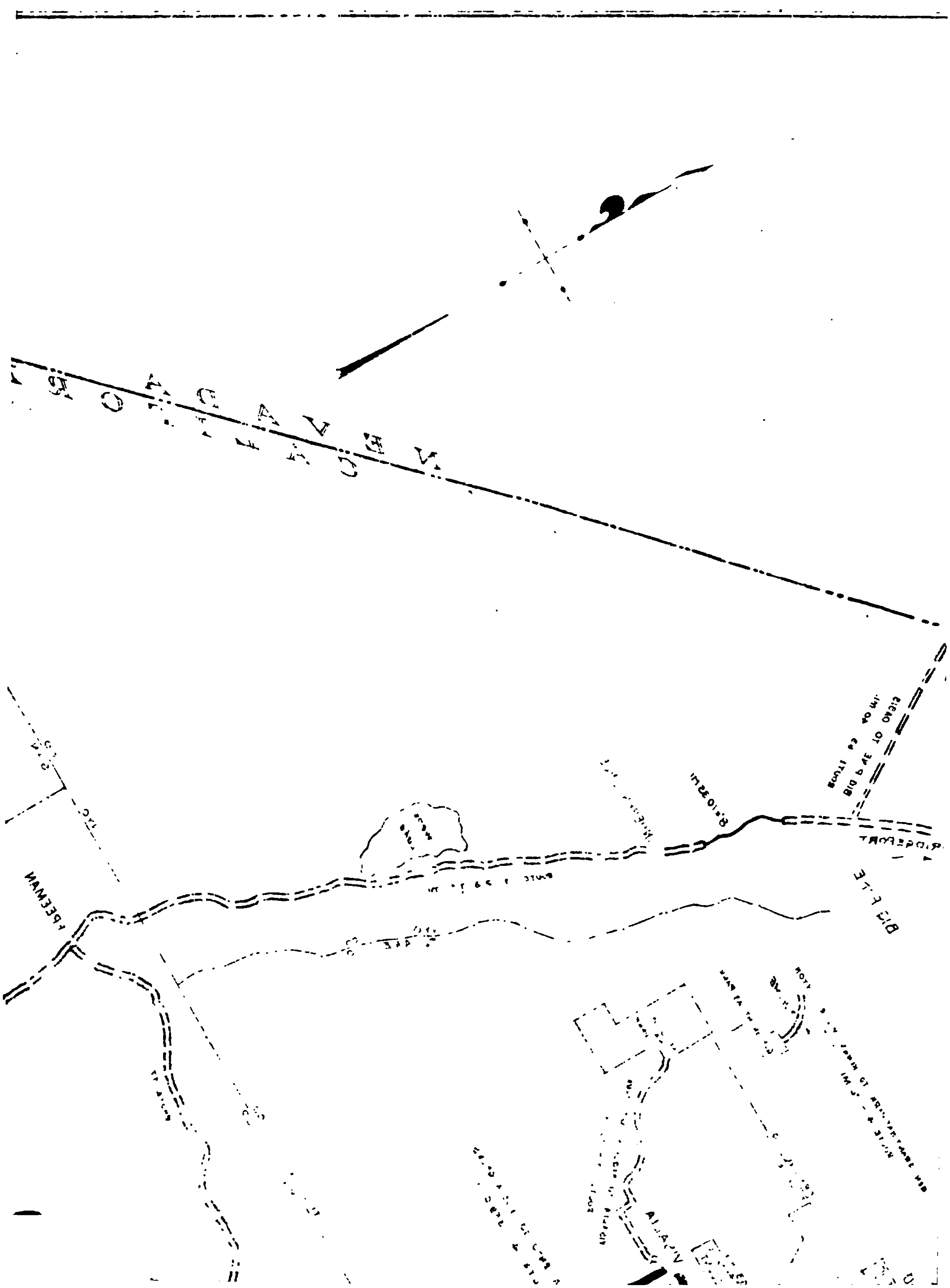
Publications Examined in ALKALI Search

1. The Cement Age, Vol. 3-13 (changed to Concrete).
2. Concrete, Vol. 1-15 (1919), and 2 of v. 17 (1920).
3. American Concrete Institute, to Vol. 15, 1919.
4. American Society for Testing Materials, v. 1-19 (1919).
5. American Institute of Chemical Engineers, v. 1-9, 1916.
6. Journal of the Franklin Institute, v. to August, 1920.
7. Journal of the American Chemical Society, to August, 1920.
8. Proceedings of the Institution of Civil Engineers, 1847 to 1907.
9. Journal of Agricultural Research, to August, 1920.
10. Chemical Engineering (Chemical Age), 1909 to 1920.
11. Chemical Abstracts, to August, 1920.
12. All available text books on concrete and materials of construction.

INDEX TO ILLUSTRATIONS



NEEDLES
BARSTOW
SAN BERNARDINO
REDLANDS
RIVERSIDE



December 20, 1920.

Good Roads Bureau,
California State Automobile Assn.,
San Francisco, California.

Attention of Mr. H. J. Brunnier, Chairman.

Gentlemen:

In accordance with your instructions of July 27, 1920, we have made an exhaustive examination of the State Highway System in California. We transmit herewith a detailed report of the results of our investigation with recommendations covering such phases of the work as seem susceptible of modification and improvement.

While it may appear that numerous features of the State Highway work in California have been strongly criticised, it has been the guiding principle to make such criticism constructive solely with a view toward a modification of past policies and better and more modern practice in future construction work.

Yours very truly,
HOWE & PETERS.

ENGINEERS' REPORT

TO

CALIFORNIA STATE AUTOMOBILE ASSOCIATION

COVERING THE WORK OF THE

CALIFORNIA HIGHWAY COMMISSION

FOR THE PERIOD

1911-1920

HOWE & PETERS
CONSULTING ENGINEERS
SAN FRANCISCO, CAL.

INDEX

I. INTRODUCTORY STATEMENT

Following the employment of the authors "to make a comprehensive examination of the State highway system and a report covering all of the facts as found," a brief summary of the main subdivisions of the plan of investigation was submitted to the Chairman of your Good Roads Committee, Mr. H. J. Brunnier, and with his approval the actual work was then commenced. This preliminary summary included:

1. Inspection trips over most of the State.
2. Obligations under the various bond issues, and completed programs.
3. Analyses of all expenditures.
4. Organization study and accounting.
5. Technical studies of pavements and principal factors contributing to failures.
6. Laboratory tests that might prove of value.
7. Cost data and maintenance studies.
8. Traffic and the Motor Vehicle Law and Tax.
9. Specific recommendations as determined by a study of the facts and data collected.

With the completion of the investigation, the general summarization given above has been covered in considerable detail.

Inspection trips covering approximately 4,000 miles of travel by automobile have been completed, and each section of State highway visited included a survey of:

1. Condition of pavement.
2. Subgrade material.
3. Drainage and drainage structures.
4. Gradients and alignment.
5. General traffic conditions.
6. Maintenance needs.
7. Incidental factors.

Through the courtesy of the Highway Commission, records showing the age, width and type of each section of paved highway were furnished on request prior to the various trips, and these aided considerably in the study of field conditions. From time to time additional data covering specific subjects such as lists of reinforced pavements, thickness and mixtures of concrete road slabs, laboratory tests of aggregate, etc., etc., together with plans, maps, forms and other general information, have been requested from the Commission and in every instance the material has been freely furnished.

To check over highway expenditures and collect the mass of cost and maintenance data required, it was arranged for our own accountants to have access to the Highway Commission's books and records and a study of the data obtained forms an important part of this report.

As a check to certain theoretical and mathematical deductions in this report, certain tests of concrete slabs and adobe soil were arranged for in consultation with and under the direction of Professor Charles Derleth, Jr., of the University of California, with Professor C. T. Wiskocil directly in charge of the testing operations.

Traffic counts were made at several points to furnish data on specific sections of highway. A more comprehensive study was made by the Automobile Club of Southern California and a similar study was therefore considered a needless duplication in the north.

Additional data was collected from such sources as the Railroad Commission, Motor Vehicle Department, Bureau of Public Roads at Washington, and a considerable volume of information was obtained from correspondence with thirty-five other states

Opportunity was also taken to make an inspection of the highway work in Oregon and Washington for the purpose of obtaining comparative data on the various types of roads constructed in these two states.

Every effort has been made to arrive at basically sound conclusions in digesting and analyzing the detail of this investigation and advantage has been taken of important contributions to highway engineering literature in comparing ultimate conclusions.

It has been the effort of the writers to give credit in every instance to those authorities from whom data or information has been obtained or from whose articles contributory facts have been utilized.

The report is divided into three parts as shown in the index and this index will be followed in regular order in the succeeding pages.

PART I

2. THE VARIOUS HIGHWAY ACTS AND FUNDS AND THE STATE HIGHWAY SYSTEM

State Highways Act of 1909 2.1

With the enactment of this law in March, 1909, a system of State Highways for California was designated to be constructed and acquired at a cost not to exceed eighteen million dollars.

A "State Highway Fund" was created in and for the State Treasury to which all moneys from the sale of highway bonds were to be credited. Such money was designated to be "used exclusively for the acquisition of rights of way for and construction of said system of State Highways." The route or routes of said highways ". . . to be selected by the Department of engineering . . . as to constitute a continuous and connected State Highway system running north and south through the State, traversing the Sacramento and San Joaquin Valleys and along the Pacific Coast, by the most direct and practicable routes, connecting the county seats of the several counties through which it passes and joining the centers of population, together with such branch roads as may be necessary to connect therewith the several county seats lying east and west of such State Highway."

It is further stipulated that "the highway constructed or acquired under the provisions of this act shall be permanent in character," the exact character or type of pavement being left to the judgment of the Department of Engineering.

A further stipulation enacted that each county in the State should pay into the State Treasury such sums each year as would equal the interest at the rate of four per cent per annum upon the entire sum of money expended within such county in the construction of said highway, less such portion of said amount expended as the bonds matured . . . shall bear to the total number of bonds sold and outstanding.

At the general election in November, 1910, this act was ratified by vote of the people and became effective December 31, 1910, and $18,000,000.00 became available in bonds for the construction of a State Highway system.

The program of construction contemplated in laying out this system of highways is clearly shown in black lines on Map No. 1 following and tabulation accompanying same and, on the map, the actual mileage of this original system of graded and paved highways completed to June 30, 1920, is designated. The mileage completed with the original $18,000,000.00 totaled in round figures approximately 1,100 miles of paved road and 400 miles of graded highway, the latter with culverts and other incidental structures.

State Highways Act of 1915 2.2

This act of May, 1915, approved by the voters at the general election in November, 1916, provided an addition to the bonded debt of the State in the sum of $15,000,000.00. Of this amount $12,000,000.00 was to construct uncompleted portions of the originally planned system and $3,000,000.00 for the acquisition, construction and improvement of certain extensions from said system of State Highways. The additional roads to be constructed are expressly described in the Act and are clearly shown in heavy black lines on Map No. 2 and tabulation accompanying. Red and orange lines designate the paved and graded portions of the new roads completed to date.

It was provided, however, "that expenses of the acquisition, construction and improvement of the extensions enumerated . . . . shall be partly borne by the county or counties in which such extensions lie; the extent and character of such division of expenses between the State and county shall rest for final determination with the State Department of Engineering. . . . ."

It is to be noted that $2,000,000.00 worth of bonds of this issue remain unsold at this date.

State Highways Act of 1919 **2.3**

This Act merely extended the funds for the completion of the highways contemplated under the two preceding acts by the addition of $20,000,000.00 to the highway funds for this purpose and an additional $20,000,000.00 for the construction of the roads shown on Map No. 3 following and accompanying tabulation. Other than surveys, no work has been started on these additional roads.

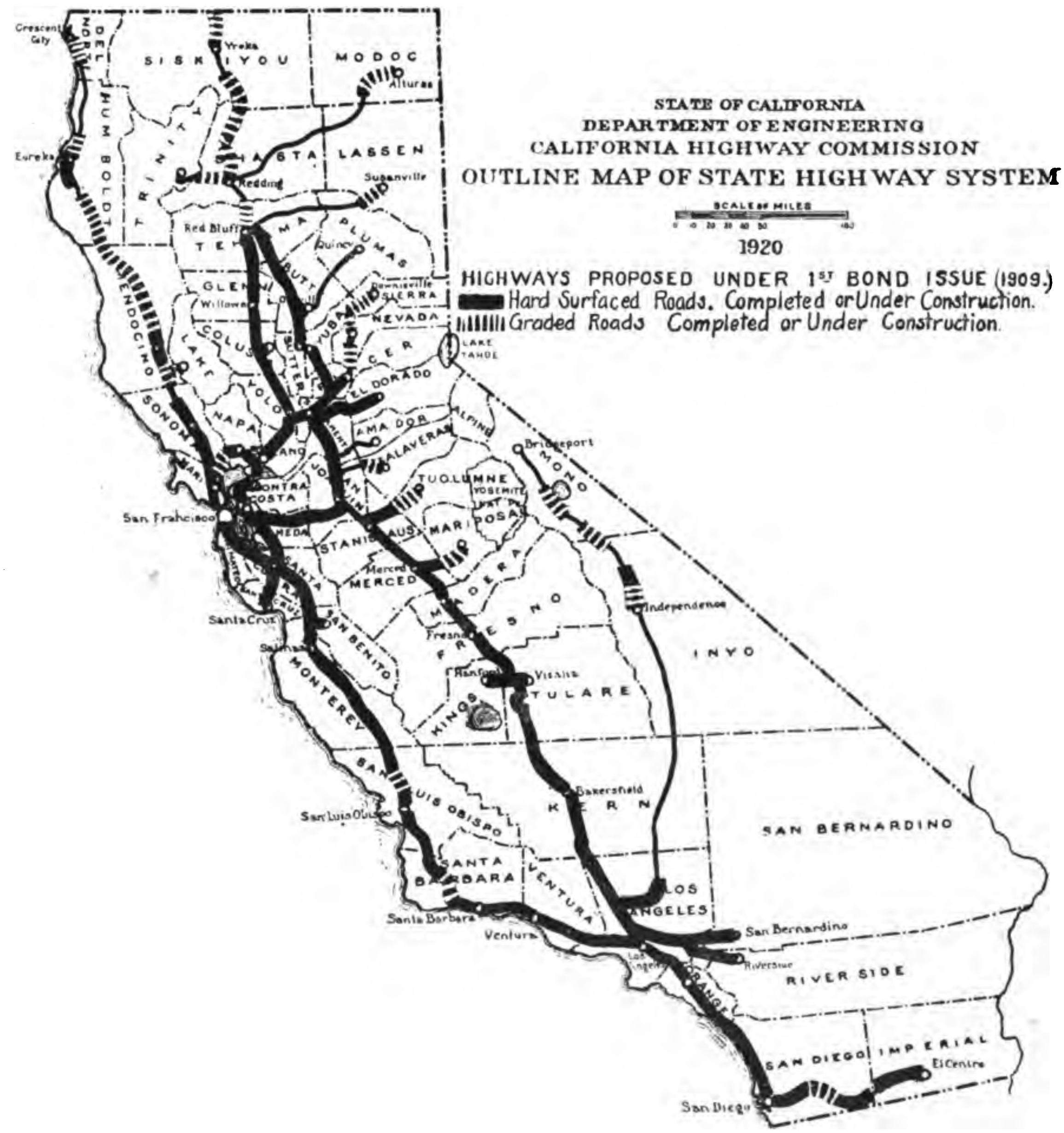
Of this $40,000,000.00, on June 30, 1920, there remained unsold bonds to the amount of $37,000,000.00 If to this be added the $2,000,000.00 unsold bonds remaining in the second highway issue, the highway fund is found to consist of $39,000,000 in bonds as of June 30, 1920

FIRST BOND ISSUE

Route	From	To	Mileage
1	San Francisco	Crescent City	371.2
2	San Francisco	San Diego	481.8
3	Sacramento	Oregon Line	291.3
4	Sacramento	Los Angeles	359.0
5	Stockton	Santa Cruz via Oakland	116.9
6	Sacramento	Woodland Junction	14.3
7	Tehama Junction	Benicia	142.7
8	Ignacio	Cordelia via Napa	38.6
9	San Fernando	San Bernardino	53.5
10	Goshen (4)	Hanford	13.2
11	Sacramento	Placerville	46.5
12	San Diego	El Centro	127.5
13	Salida	Sonora	49.2
14	Albany	Martinez	20.6
15	Williams	Colusa	8.7
16	Hopland	Lakeport	19.3
17	Roseville	Nevada City	33.4
18	Merced	Mariposa	39.2
19	Rt. 9 West of Claremont	Riverside	17.7
20	Redding	Weaverville	50.0
21	Rt. 3 near Richvale	Oroville	7.0
22	San Juan Bautista	Hollister	7.1
23	Saugus	Bridgeport	337.5
24	Rt. 4 near Lodi	San Andreas	36.6
25	Nevada City	Downnieville	47.0
28	Redding	Alturas	151.1
29	Red Bluff	Susanville	100.0
30	Oroville	Quincy	67.0*
34	Rt. 4 near Arno	Jackson	34.4
		Total	3,082.3

*Route 30 has been abandoned, and Route 21 extended to cover approximately same mileage.

Map No. 1.


STATE OF CALIFORNIA
DEPARTMENT OF ENGINEERING
CALIFORNIA HIGHWAY COMMISSION
OUTLINE MAP OF STATE HIGHWAY SYSTEM
SCALE of MILES
1920
HIGHWAYS PROPOSED UNDER 1ST BOND ISSUE (1909.)
Hard Surfaced Roads. Completed or Under Construction.
Graded Roads Completed or Under Construction.
SISKIYOU
MODOC
LASSEN
Alturas
Yreka
Eureka
Redding
Susanville
Red Bluff
Quincy
Willows
LAKE TAHOE
Bridgeport
MONO
San Francisco
Santa Cruz
Merced
MERCED
Fresno
Visalia
TULARE
Independence
INYO
Bakersfield
KERN
SAN BERNARDINO
San Luis Obispo
SANTA BARBARA
VENTURA
Santa Barbara
Ventura
San Bernardino
Riverside
RIVER SIDE
SAN DIEGO
IMPERIAL
El Centro
San Diego

ADDITIONAL HIGHWAYS ADDED IN SECOND BOND ISSUE

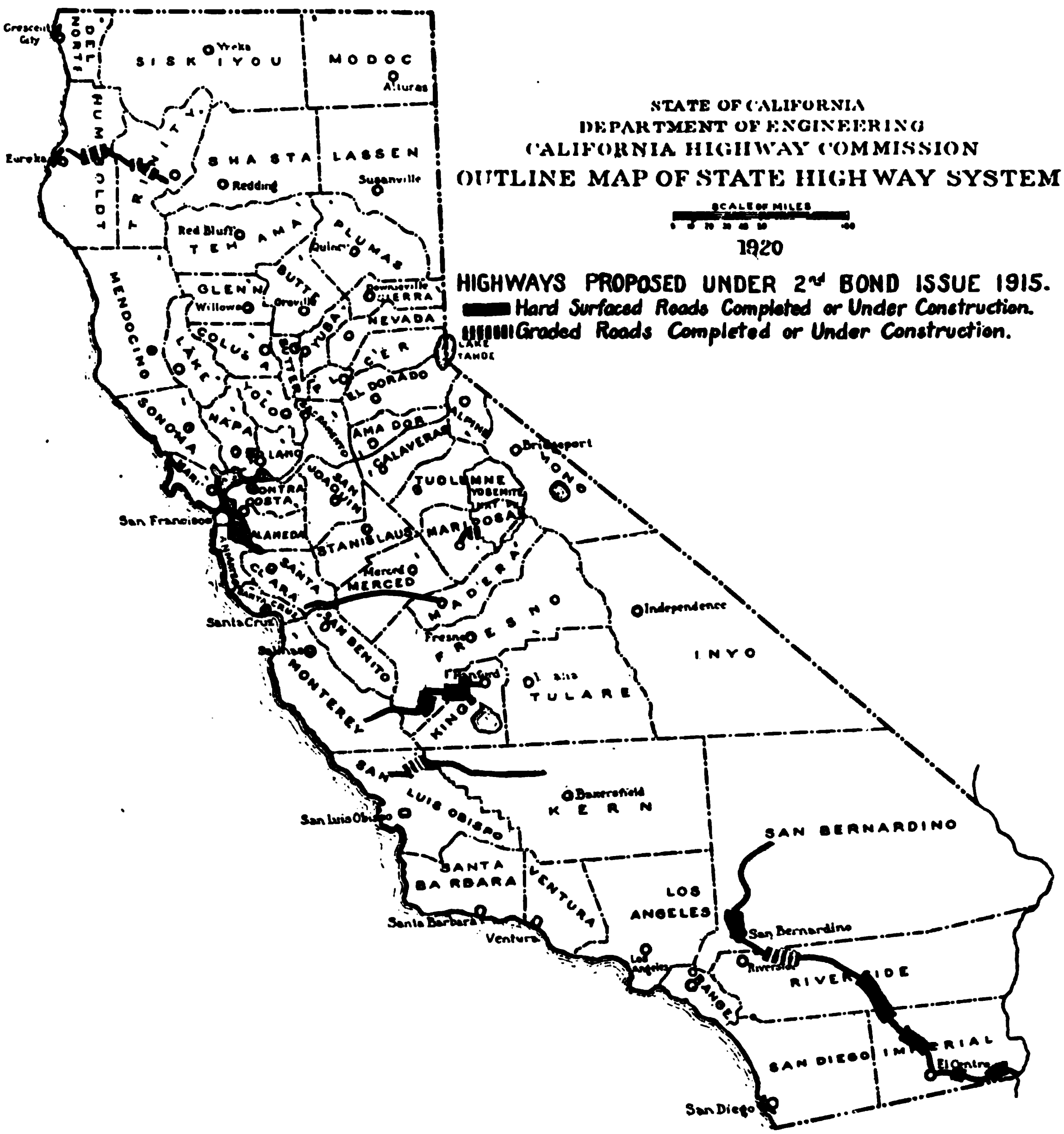
Route	From	To	Mileage
10	Hanford	San Lucas	98.25
18	Mariposa	El Portal	32.60
20	Douglas City	Rt. 1 Arcata	102.00
26-27	San Bernardino	Yuma via El Centro	195.86
31	San Bernardino	Barstow	76.33
32	Rt. 4 near Califa	Gilroy	83.45
33	Rt. 4 near Bakersfield	Paso Robles	91.22
		Total	679.71

ADDITIONAL HIGHWAYS ADDED IN THIRD BOND ISSUE

Route	From	To	Mileage
58	Mojave	Needles (via Barstow)	255
60	Oxnard	San Juan Capistrano	86
57	Santa Maria	Freemans (via Bakersfield)	202
55	San Francisco	Santa Cruz	67
53	Rio Vista	Fairfield	24
*1 37	Auburn	Verdi	95
15	Ukiah	Tahoe City	212
*2 38	Truckee	Emigrant Gap	
1	Crescent City	Oregon Line	40
51	Santa Rosa	Shellville	24
63	Big Pine	Oasis	40
*3 11	Placerville	Sportsman's Hall	10
21	Oroville	Quincy	27
*4 41	Gen. Grant National Park	Kings River Canyon	20
49	Calistoga	Lower Lake	32
64	Mecca	Blythe	100
50	Rumsey	Lower Lake	35
62	Azusa	Pine Flats in San Gabriel Canyon	10
61	La Canada	Mt. Wilson Road via Arroyo Seco	10
59	Lancaster	Baileys	40
48	McDonalds	Mouth of Navarra River	47
56	Carmel	San Simeon	97
46	Klamath River Bridge (Route 3)	Route 1 near Mouth of Klamath River	177
29	Susanville	Nevada State Line	53
22	Pacheco Pass Road into Hollister		8
10	Visalia	Sequoia National Park	36
43	Deep Creek	Metcalf Creek	14
47	Orland	Chico	20
52	Tilburon	Alto	5
54	Near Michigan Bar	Drytown	12
		Total	1,798

*1 95 miles maintained under Special Appropriation Roads.
*2 15 " " " " " "
*3 10 " " " " " "
*4 14 " " " " " "

Map No. 2.


STATE OF CALIFORNIA
DEPARTMENT OF ENGINEERING
CALIFORNIA HIGHWAY COMMISSION
OUTLINE MAP OF STATE HIGHWAY SYSTEM
SCALE OF MILES
1920
HIGHWAYS PROPOSED UNDER 2nd BOND ISSUE 1915.
Hard Surfaced Roads Completed or Under Construction.
Graded Roads Completed or Under Construction.
Crescent City
Eureka
SISKIYOU
MODOC
Alturas
SHASTA
LASSEN
Redding
Susanville
Red Bluff
TEHAMA
PLUMAS
Quincy
GLENN
Willows
BUTTE
Oroville
SIERRA
NEVADA
MENDOCINO
COLUSA
LAKE
LAKE TAHOE
EL DORADO
SONOMA
NAPA
YOLO
AMADOR
ALPINE
CALAVERAS
Bridgeport
MONO
TUOLUMNE
CONTRA COSTA
SAN JOAQUIN
San Francisco
ALAMEDA
STANISLAUS
MARIPOSA
MERCED
Merced
SANTA CLARA
MADERA
FRESNO
Fresno
Independence
INYO
Santa Cruz
SAN BENITO
MONTEREY
KINGS
TULARE
SAN LUIS OBISPO
San Luis Obispo
Bakersfield
KERN
SAN BERNARDINO
SANTA BARBARA
Santa Barbara
VENTURA
Ventura
LOS ANGELES
San Bernardino
Riverside
RIVERSIDE
ORANGE
SAN DIEGO
IMPERIAL
El Centro
San Diego

Map No. 3.


STATE OF CALIFORNIA
DEPARTMENT OF ENGINEERING
CALIFORNIA HIGHWAY COMMISSION
OUTLINE MAP OF STATE HIGHWAY SYSTEM
SCALE OF MILES
1920
HIGHWAYS PROPOSED UNDER 3rd BOND ISSUE 1919.
Crescent City
Yreka
SISKIYOU
MODOC
Alturas
Eureka
HUMBOLDT
TRINITY
SHASTA
LASSEN
Redding
Susanville
Red Bluff
TEHAMA
PLUMAS
Quincy
MENDOCINO
GLENN
Willows
Oroville
BUTTE
SIERRA
NEVADA
LAKE TAHOE
LAKE
COLUSA
EL DORADO
YOLO
SONOMA
NAPA
AMADOR
ALPINE
CALAVERAS
Bridgeport
MONO
TUOLUMNE
YOSEMITE
CONTRA COSTA
San Francisco
ALAMEDA
STANISLAUS
MARIPOSA
SANTA CLARA
Merced
MERCED
MADERA
Independence
Santa Cruz
SAN BENITO
FRESNO
Fresno
INYO
Salinas
MONTEREY
Hanford
Visalia
TULARE
KINGS
SAN LUIS OBISPO
San Luis Obispo
Bakersfield
KERN
SAN BERNARDINO
SANTA BARBARA
VENTURA
LOS ANGELES
Santa Barbara
Ventura
San Bernardino
Los Angeles
Riverside
RIVERSIDE
ORANGE
SAN DIEGO
IMPERIAL
El Centro
San Diego

Tabulations of Highway Construction 2.4

Tables No. 1 and No. 2 following give the total mileage of paved and graded highways completed to June 30, 1920.

Table No. 3 is a summation of highways under contract but not completed on June 30, 1920.

In connection with completed highway construction it is of interest to note the following bridge expenditures on the State Highway system:

By State	$2,651,000.00
By counties	4,520,000.00

The following is the status of the complete present day highway program as of June 30, 1920:

	Miles
Paved highways completed or under construction	1,580.71
Graded highways completed or under construction	732.54
Highways to be constructed to complete entire system	3,246.75
Total	5,560.00
Approximately 200 miles of county built highways have been taken over by the State	200.00
Grand total	5,760.00

TABLE I.

STATE HIGHWAY SYSTEM

AS OF

JUNE 30, 1920.

Paved and Graded roads including highways constructed by Counties and subsequently incorporated into State System.

CONCRETE BASE WITH ASPHALT SURFACE	76.38	MILES
CONCRETE BASE WITH OR WITHOUT THIN BITUMINOUS SURFACE	1292.83	"
BROKEN STONE BASE WITH TOPEKA SURFACE	16.26	"
OILED MACADAM	204.96	"
BITUMINOUS CONCRETE	16.45	"
GRADED	400.33	" (1)
TOTAL	2007.21	"

(1.) This mileage does not include approximately 750 miles of graded road taken over from the State Department of Engineering.

TABLE II

STATE HIGHWAY COMPLETE.

JUNE 30TH 1920.

NUMBER OF MILES

	WIDTH OF PAVEMENT IN FEET						TOTAL
	12'	15'	18'	20'	22.5'	24'	
CONCRETE BASE	24.09	610.41	35.90	42.77			713.17
CONCRETE BASE THIN BITUMINOUS TOP	13.40	475.50	71.09	14.64			574.63
CONCRETE BASE ASPHALT TOP		22.87	8.14	11.98	.31	10.70	54.00
OIL MACADAM	5.27	27.76					33.03
ASPHALT ON MACAD.			6.43	5.05		5.06	16.54
TOTALS	42.76	1136.54	121.56	74.44	.31	15.76	1391.37

15.09 MILES 8 CONCRETE PAVEMENT IN INYO CO., OMITTED.

TABLE III

STATE HIGHWAY INCOMPLETE.

JUNE 30TH 1920.

NUMBER OF MILES

	WIDTH OF PAVEMENT IN FEET					TOTAL
	15'	18'	20'	22.5'	24'	
CONCRETE BASE	148.36	6.60	19.38			174.34

SURFACING ONLY

	WIDTH OF PAVEMENT IN FEET					TOTAL
	15'	18'	20'	22.5'	24'	
THIN BITUMINOUS TOP.	133.96					133.96
ASPHALT TOP	5.47		4.23			9.70

3. ORGANIZATION

Creation of the State Highway Commission 3.1

While the California Highway Commission came into existence early in the year 1911, under certain statutes providing for the appointment of a highway engineer and such assistants as might be necessary, the actual recognition by law of the California Highway Commission, together with a specific explanation of the powers and duties of said commission, was not established until May, 1917. Sections 9 and 10 of the Statutes of 1917 made the following provisions:

> The said California Highway Commission shall forthwith assume and have and exercise all of the powers and duties of the State Engineer relating to State roads and State highways and other roads and highways heretofore by law conferred or imposed upon said State Engineer, and the said State Engineer shall immediately relinquish and transfer to the said California Highway Commission all funds, papers, maps, records and other documents of the Department of Engineering relating to the roads and highways of the State, and thereafter the State Engineer shall have no further duty, power or responsibility with regard to roads and highways, save only such as shall devolve upon him as a member of the Advisory Board of the Department of Engineering. Said California Highway Commission shall have the supervision and direction of all State roads and State highways now existing, and the improvement, maintenance, repair and protection thereof, and have charge of and perform all other duties relating to State roads and State highways which may be imposed upon said Commission by said Advisory Board. The Highway Engineer shall be the chief executive officer of the California Highway Commission and shall perform such duties as may be imposed upon him by the California Highway Commission which are not in conflict with any duties which may be placed upon him by said Advisory Board. . . . .
>
> (a) Make such investigations as will put at the service of the State the most approved methods of highway improvement.
>
> (b) Compile statistics relative to the public highways of counties and municipalities.
>
> (c) If deemed expedient by said Commission and at the expense of the applicants, either in whole or in part, as determined by said Commission, aid county, road or boulevard district or division and municipal authorities, in establishing grades and road drainage systems and advise with them as to the construction, improvement and maintenance of highways and bridges. . . . .
>
> (d) Investigate and determine upon the various methods of road construction adapted to the different sections of the State, as to the best methods of construction and maintenance of highways and bridges, and make such experiments in relation thereto from time to time as said Commission deems expedient.
>
> (e) Aid at all times in promoting highway improvement throughout the State.
>
> (f) Have the power to call upon any State, county or municipal official to furnish said Commission with any information contained in his office which relates to, or is in any way necessary to, the proper performance of the work of said Department of Engineering.

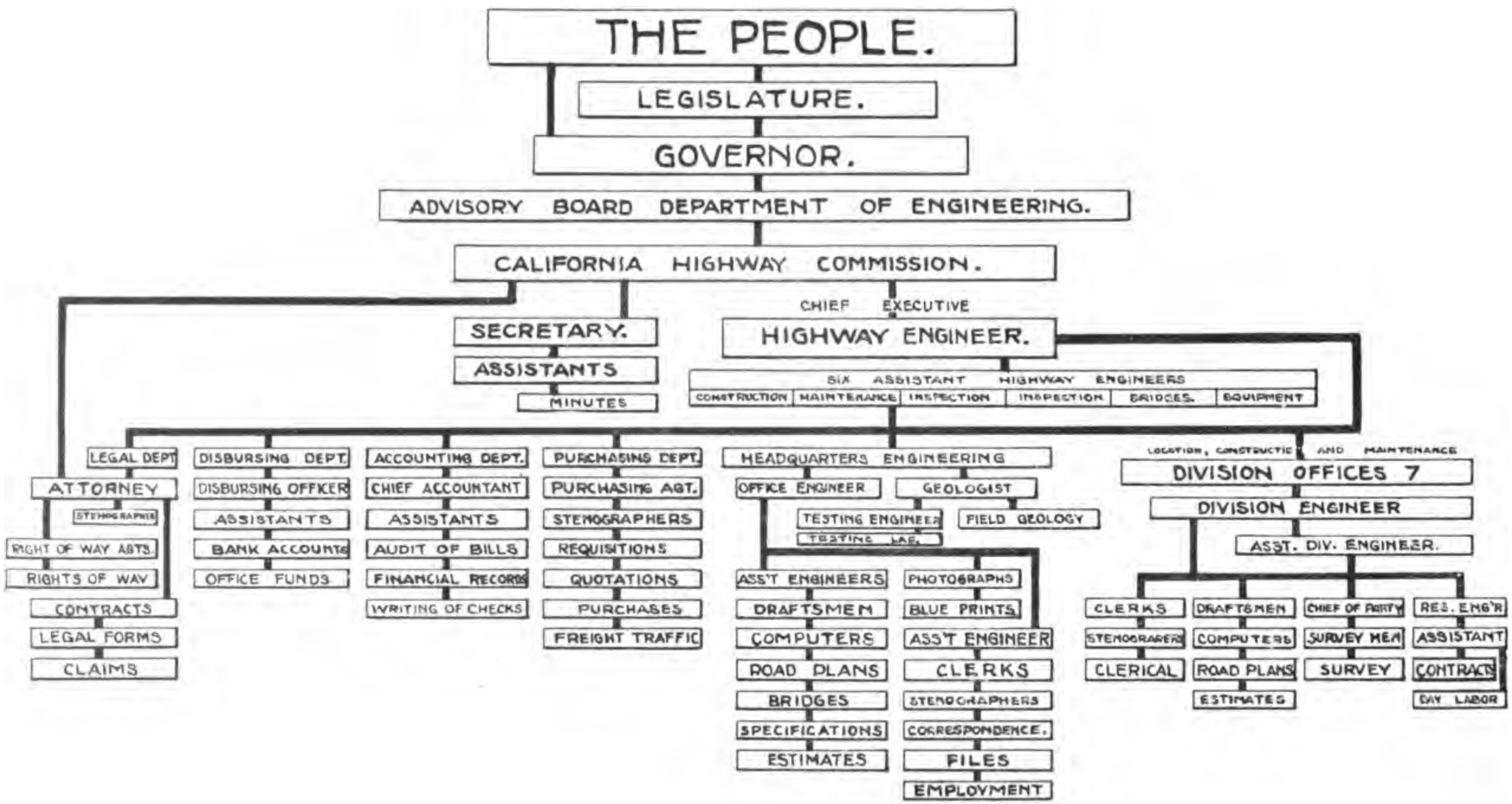
General Plan of Organization 3.2

The administrative functions are carried on by the three Highway Commissioners and the State Highway Engineer. The secretary and the attorney for the Commission, having the relative functions implied, are the completing units of the administrative body.

At the general headquarters at Sacramento the State Highway Engineer has six assistants to whom are delegated the specific duties somewhat briefly outlined in the plan of organization.

Actual construction supervision in the field is carried on by seven Division Engineers with their assistants. Each Division has a small headquarters force and the necessary field assistants, including survey parties. Resident engineers, assistant resident engineers and superintendents of construction are directly in charge of work in the field.

ORGANIZATION CHART
California Highway Commission



Each Division is organized as a unit within itself, equipped to make all location surveys and to carry on supervision of contract work, construction by force account, and general patrol and maintenance operations, with minor accounting duties. The Division Engineer naturally reports directly to the State Highway Engineer at Sacramento.

The only factor of particular interest in the conduct of the Highway Commission organization at this time, is a recently attempted policy of calling the Division Engineers to Sacramento headquarters once in each month for a general conference covering the various problems that arise in the field and headquarters and the general policies of the Highway Commission, etc., etc. It is very probable that these monthly meetings will be productive of an increase in the "esprit de corps" throughout the entire organization which in turn naturally makes for better and more harmonious working conditions and in the last analysis, better and cheaper work.

The organization chart on the page preceding, taken from the first biennial report of the California Highway Commission and modified to include the change from one to six Assistant Highway Engineers at Sacramento Headquarters, is a graphical exposition of the details of this organization.

Increased Division Responsibility 3.3

Through a headquarters policy which can only be classed as narrow and shortsighted, the responsibility of the Division Engineers in the various divisions of the State is so circumscribed that at times the work resolves itself into mere routine such as the transmission of estimates, bill schedules, work orders, purchase orders and general requests for headquarters' approval. The various forms of red tape through which it is necessary to go in order to secure approval for some of the simplest changes, modifications, or purchases, and in consequence the lost time and demoralization to an organization waiting to go ahead and accomplish things is a source of common criticism among State Highway employes and contractors engaged in building the highways.

The position of Division Engineer is an important one, but lack of authority to decide questions and the necessity for referring the most minor items to Sacramento Headquarters for decision, robs the Division of its individuality, takes away the responsibility that rightfully belongs to the position, kills the initiative of the official in charge and therefore affects the entire organization.

The question of increased responsibility and proper latitude for the State Division Engineers and assistants is highly important in the interest of better and more efficient service.

In this latter connection, a revolving fund **sufficiently large** to allow of direct payment of expense accounts, freight advances and merchants' bills should be assigned to each Division office, so that the practice of a Division Engineer paying State obligations out of his own pocket may not be necessary, nor should he be compelled to act as an intermediary to "stand off" State creditors who often wait months at a time for settlements of such vital items as board and lodging, stock feed, general supplies, etc.

"Benzine Camp" 3.4

It is beyond any reasonable requirement to expect to place in each position of varying responsibility in an organization the size of that administered by the California Highway Commission, men exactly suited to the work imposed or capable of carrying on with a proper degree of success certain classes of work.

To attempt to maintain in certain positions of responsibility men with capabilities foreign to the particular detail of that position, in the hope or expectation that time and experience may fit the man to the work, is rarely productive of the result desired and the general effects of such a policy upon the rank and file of the organization is extremely bad.

The successful conduct of many of our large corporations of today is closely bound up in the degree of surety with which the proper men are directed into the channels of operations most suited to their capabilities.

It is the belief of the writers that more attention to this important detail of administration on the part of the Highway Commission might be productive of excellent results throughout the entire organization.

In this connection, one detail adopted by General Pershing in directing the activities of that tremendous organization of over 2,000,000 men, known as the American Expeditionary Force in France, may point the way to the adoption of some more uniform and efficient method of classification on the part of the State Highway and Civil Service Commissions.

The greatest and most particular concern in France was to secure able leaders for the fighting forces and the fighting line furnished the test. Vacillation, hesitancy, inability to reach decisions, deviation from orders, improper or lack of attention to the welfare of men and weapons —these and many other characteristics even more minor, furnished a sufficient cause for immediate removal from that particular command. All of which is most usual and expected, but the remaining procedure is not.

It was realized that an officer unsuited to lead fighting troops might have capabilities along other lines, and it would be the part of economy both in man power and money to realize on the investment in salary and training which the Government had incurred in such officer. To effect this conservation, a classification depot was established and an examining board of experienced officers appointed to re-assign, where possible, all officers sent to the depot. This depot was popularly known as the "Benzine Camp." The exact figures of the work are not available, but it is known that the numbers of men re-classified successfully is a large proportion of all those sent to the depot. The far-sighted policy is the outstanding feature.

The application of a similar arrangement within the organization of the Highway Commission should present no impossibilities. It is principally a question of a complete review and survey of the personnel of the organization as it exists and the creation of a small committee to receive and review reports and recommendations on, and records of efficiency of, individuals of the personnel.

A review and re-rating of certain Divisions in the State organization is needed at this time if the complaints and criticisms freely offered by business firms, contractors and even Division employees are to be considered as an indication of unsatisfactory conditions and hence lowered efficiency. Such criticism takes on added weight when the record of the same Division under a former administrative personnel has been conspicuous for marked efficiency of service and well known loyalty of organization.

In regard to organization promotions, it is a matter of common knowledge and of strong justifiable criticism that although the present State Highway organization has been in existence since 1912 and has had, and still retains within its ranks of Assistant Division Engineers, some of the most capable men in the profession, in only one known instance has an Assistant Division Engineer been promoted to the grade of Division Engineer, despite the fact that three of the former Division Engineers have voluntarily resigned and left the service, thus creating vacancies to be filled by promotion.

It is our belief that initiative and loyalty in an organization are stimulated by any system which practices reward for faithful and capable service and conversely the morale of an organization is adversely affected by the lack of opportunity for promotion or the maintenance of incapable officials in positions of authority.

Administration and Overhead Costs 3.5

Total funds made available to the Highway Commission to June 30, 1920, as shown on their books, are as follows:

1st Highway Bonds	$18,002,129.00
*2nd Highway Bonds	13,000,025.00
3rd Highway Bonds	3,000,000.00
Special Appropriations	265,308.36
County Contributions	632,120.73
Federal Aid	568,183.77
Motor Vehicle Taxes	6,539,563.21
Total	$42,007,330.07
Deferred liabilities and reserves amount to	901,905.31
Total	$42,909,235.38

*Bonds to the amount of $2,000,000 of the 2nd Highway Issue remain unsold.

Total expenditures of all kinds to June 30, 1920, have reached the sum of	$41,790,884.41
Funds available and cash accounts total	1,118,350.97
Total	$42,909,235.38

These expenditures may be subdivided as follows:

Highway construction and engineering	$31,007,654.05
Highway maintenance and engineering	4,592,720.94
Expenditures for equipment (maintenance, construction, stable, motor, engineering, shop and laboratory)	1,131,064.75
Sand plants, maintenance yards, office building, powder magazine, etc.	199,790.40
Incidental expenditures and charges	342,793.42
County contributions	632,120.73
Discount, 3rd Highway Bonds	222,160.50
Maintenance Administration	525,788.75
Construction Administration	3,136,790.87
Total	$41,790,884.41

The following tabulation is a segregation of expenditures grouped from the foregoing figures with maintenance supervision estimated at the same percentage as construction supervision:

Administration and Overhead	8.76%	$ 3,662,579.62
Field Engineering, Inspection	4.43%	1,849,069.44
Equipment Plants, Yards, etc	3.19%	1,330,855.15
Miscellaneous Expenditures	1.35%	564,953.92
Construction, Maintenance and County Contribution Expenditures	82.27%	34,383,426.28
Total of	100.00%	$41,790,884.41

Total overhead costs are therefore 13.19% of total expenditures and it is apparent that this is high. If, to total construction costs be added county bridge expenditures in which the Highway Commission supervised construction and passed on plans, this percentage will be slightly reduced. Surveys of new roads when later charged against the construction will effect an additional small reduction, but it is estimated that the percentage for administration and engineering in the last analysis will approximate more than 12%, which is still somewhat excessive when compared with the percentage rates charged by engineers in private practice in California and the rates recommended by the American Institute of Consulting Engineers.

TRIAL BALANCE, CALIFORNIA STATE HIGHWAY COMMISSION
JUNE 30, 1920

Highways completed and in process		$31,007,654.05	
Construction equipm't accts.	$ 559,672.22		
Sand Plants	35,792.46		
Maintenance Yards	103,744.70		
Powder Magazines	10,654.66		
Stores Account	64,833.38		
Motor V. Chgs. paid from Highway Funds to be credited later	72,392.54		
Administration Expense	3,136,790.87	$ 3,983,880.83	
Office Bldgs.		7,261.63	
Total Expenditures Highway Fund			$34,998,795.91
Highway Maintenance		$4,592,720.94	
Maintenance Equipment	$613,729.48		
Stores Account	26,418.83		
County Expense	21,892.92		
Administrative Expense	525,788.75	$1,187,829.98	
Total Expenditures Motor Vehicle Fund			$5,780,550.92
Co., Municipal and Private Contributions			632,120.73
Special State Appropriations Expenditures			97,683.99
Federal Aid:			
Expenditures for Projects	$ 59,571.76		
Discount on 3rd State Highway Bonds	222,160.50		$281,732.26
Cash Accounts	$138,012.65		
Office Fund		$ 125.00	
Office Fund Div.		42,500.00	
Bank D. O. Mills & Co.		38,777.34	
Farm & Mach. Bank		29,000.00	
Calif. National Bank		1,780.76	
Calif. National Bank General Fund		15,292.13	
Calif. National Bank Rev. Fund		10,537.42	
Funds Available	$980,338.32		
1st State Highway		$ 100,000.00	
2nd State Highway		55,179.09	
3rd State Highway		3,819.28	
Motor Vehicle Fund		367,264.07	
Special State Appr. Act of 1917, Chap. 746		167,624.37	
Federal Aid		286,451.51	$1,118,350.97
TOTAL DEBITS			$42,909,235.38

1st State Highway Fund	$18,000,000.00		
1st State Highway Fund Premium	2,129.00		
2nd State Highway Fund	13,000,000.00		
2nd State Highway Fund Premium	25.00		
3rd State Highway Fund	3,000,000.00	$34,002,154.00	
Borrowed from Motor Vehicle Fund		506,000.00	
Total Available for Highway Expenditures			$34,508,154.00
Motor V. Apportionments		$6,539,563.21	
Loaned to Highway Fund		506,000.00	
Total Available for Motor Vehicle Fund Expense			$6,033,563.21
Co., Municipal and Private Contributions			$632,120.73
Special State Appropriations			
Chapter 704, Act 1915		$ 7,321.86	
Chapter 708, Act 1915		7,986.50	
Chapter 746, Act 1917		250,000.00	
Total			$265,308.36
Federal Aid			$568,183.77
Deferred Liabilities			
Vouchers Payable		$747,960.64	
Unclaimed Wages			
Highway Funds	3,230.51		
Motor Vehicle Funds	714.16	3,944.67	
Total Deferred			$751,905.31
Reserves			
1st State Highway Fund Reserve		$100,000.00	
2nd State Highway Fund Reserve		50,000.00	
Total Reserves			$150,000.00
TOTAL CREDITS			$42,909,235.38

Accounting and Cost Keeping

3.6

In the course of the examination of California State Highway records our accountants spent considerable time at Sacramento Headquarters, collecting and compiling data pertinent to this investigation.

Among other things, it was our desire to secure accurate cost data on the various items of a State Highway contract, and we were particularly interested in analyzing the cost from year to year of the cement concrete pavements as distinguished from other items of the work.

Before discussing the steps involved in taking off any cost data from State Highway records, it may be well to state that it is the expression of the California Highway Commission that their accounts are kept purely for their own information regarding the status of the various funds and that it is primarily the function of the Board of Control to keep all of the State accounts, including that of the highway funds.

Our interest in this was not a question as to whether the duties of the California Highway Commission included the keeping of comprehensive data on expenditures, and the establishment of the above fact is not in question. It seems, however, that if accounts are kept by the Highway Commission, one of their principal interests would lie in being able from time to time, **with a minimum amount of effort,** to ascertain unit costs on various items of State Highway construction. That this is not possible was amply demonstrated by the work of our accountants in securing the data desired in this investigation.

As a demonstration of the difficulty in securing detailed costs, we may take the example of the effort to segregate unit costs for concrete pavement on each contract completed by the Highway Commission to June 30, 1920. It is necessary to explain that a ledger account is carried on each contract in which are entered the various contract items and prices, together with the costs of materials, engineering expense, and miscellaneous charges. **No attempt is made upon the completion of a contract to segregate and group together the various accounts entering into the cost of any unit of the work,** and to secure this information involved the separation and classification of hundreds of items, summarizing the same, and finally balancing with the total charges against the contract.

On contracts Nos. 1 to 176 material and other charges had been entered in the ledger accounts in sufficient detail to permit the final segregation of the same to unit items of construction, with the exception that wherever contract work had been taken over and completed by the State forces, it was practically impossible without weeks of additional labor, to secure the desired data.

Beyond contract No. 176, entries in the ledger were made grouping together various classes of materials, and to separate these properly so that unit costs could have been obtained would have entailed the employment of the accountants for a period of two to three months additional to the time consumed. The extra time referred to is not a matter of guess work, but is an estimate made after a thorough examination of the work involved.

It is our recommendation that in keeping the record of each contract job, two additional columns be added to the present ledger account and that in the first of these columns be entered the figures of the actual cost of each unit. It is estimated that this work could be done upon the completion of each contract by a single employee in one to two days' time, and as only a few contracts are completed each year, it is apparent that the expense involved is of minor importance. In the second column we would recommend that the preliminary estimate of each contract be set down opposite the figures of each unit of work.

Such a record would provide an excellent comparison sheet of work accomplished and the dissemination of the information throughout the organization would not only furnish data for future estimates, but would have a tendency to stimulate competition in the various field operations, particularly where force account work was in progress.

In regard to day labor work carried on by State forces, it is an impossibility, without securing final reports from the various Division Headquarters, to obtain any unit costs from the records of the State Highway Commission at Sacramento. While some three hundred day labor contracts have been undertaken by the State, it was possible to secure unit costs on only the few sections discussed in this report under the caption "Day Labor versus Contract Work."

It is apparent that the California Highway Commission can have no exact information relative to unit costs on their day labor operations except in such isolated instances as noted, and this information would seem to be of vital importance in view of the fact that the State has expended a total of $6,909,577.27 in such work. It is our recommendation that a ledger account on day labor work, similar to that recommended for contract work, be kept by the Commission so that this very much disputed and discussed question of day labor versus contract work may easily be determined as a profitable or unprofitable operation.

Referring again to the change which took place in entering ledger accounts beyond contract No. 176: It is our opinion that a published regulation, giving exact instructions as to just how all entries and books of the Commission should be kept, could be made available to all employees of the Accounting Department, so that this work would proceed more systematically along organization lines.

Equipment Accounts 3.7

It is probable that this discussion should be included with that of "Accounting and Cost Keeping," but the subject is such an important one and so distinct that we are making a separate item of the discussion in this report.

It will be noted in the tabulation of expenditures that $1,131,064.75 has been expended by the Commission in the purchase of equipment of all kinds. There has been added to this, by donation from the Federal Government, a great amount of excess war equipment, so that the cost value of all equipment handled must approach, very closely, the $2,000,000 mark.

It is of interest to note that the California Highway Commission has no equipment account to include repairs and sinking fund. Various items of equipment are purchased from time to time out of either the highway or maintenance funds and are used on this work until worn out, without any charges being entered in the regulation way against the various pieces of work on which the equipment is employed.

From an engineering standpoint this is somewhat startling as it is apparent that the true costs of any work on which this equipment is employed are not obtainable, due to the lack of provision either on the part of the Highway Commission or the Board of Control, of an equipment account. Yearly equipment inventories are required by the State and are made up in the division offices of the Highway Commission and submitted in great detail to the Sacramento headquarters, where the same are grouped together and turned over to the Board of Control. Instructions regarding the making of this inventory have been published by the State and are carefully followed by the Highway Commission in submitting their yearly report. These instructions include certain arbitrary percentages of depreciation to apply to the items of equipment, with the result that much of the highway equipment is completely depreciated long before its actual term of useful life has expired, and from an examination of these instructions it is apparent that no true knowledge of the actual life of the great majority of construction tools is known. **The arbitrary rates of depreciation used are shown by practice to be worthless.**

There are, therefore, two important developments of this lack of equipment account in the California State Highway operations which may be summed up as follows:

1. Inability to determine the true cost of work on which State equipment is employed.
2. Inability to depreciate equipment in accordance with actual performances.

The development of an equipment account is important in providing a means for the replacement of various tools when they become worn out. Under the present practice, requests for new equipment are submitted and approved without any knowledge as to the behavior of such equipment in actual work. No comparative data is obtainable to determine the best type of any particular machine in use except by intermittent and sporadic reports in isolated cases by the field force. That this is a handicap in the purchase of new equipment is apparent.

Minor repairs to tools, occurring during the progress of the work are made and become a charge against such work, but major shop repairs are paid for out of the general funds and are not distributed to work done.

To establish an equipment account is a subject requiring considerable thought and investigation, and while we are prepared here to make certain recommendations, these are by no means final nor conclusive, but may serve as a basis for the serious consideration of the California Highway Commission.

The first thing that is vitally necessary is the creation of a method of charging against each piece of work, based on the tools actually used in that work, a cost that will include the proper amount of depreciation and the proper portion of repairs to each tool. A somewhat arbitrary rate of depreciation will have to be assumed in the start of this account which can be corrected in years to come by reference to actual performance. The same statement will apply also to repairs. The first table following is a depreciation table arrived at by a joint conference of highway officials, contractors and equipment dealers in Wisconsin during the past year, and this table is probably as accurate as any obtainable at the present time. The second table is a tabulation showing the economic length of life in years, annual shop repairs, and annual field repairs to contract equipment, as derived by the Committee on Methods of the Associated General Contractors of America. Either of these schedules will furnish a satisfactory basis for the establishment of the operation.

It is a matter of little concern at this time as to what tabulation of repairs and depreciation is utilized in opening an equipment account, and it is probable that State records may be obtainable from the field force which would provide a basis for such tabulation.

It is recommended that the California Highway Commission request from the Board of Control an appropriation of a sum, sufficient to cover estimated equipment purchases for the next twelve months, and estimated repairs to equipment on hand for the same period; this appropriation to be the nucleus of an account to which charges for repairs for depreciation of equipment used on every piece of work will be credited and all moneys appropriated for new work will carry an estimate sufficient to cover these charges. Upon the completion of any work on which State owned equipment is used, the proper charge will be entered against the work and the actual money involved will be credited to the equipment account.

Adjustments to the tabulated percentages of depreciation and interest can be made every year or every two years, so that the equipment account in a short period of time will become self-sustaining.

It is not necessary to enlarge upon the benefits to be derived in the operation of this account, and it is apparent that what minor additional expense will be entailed will more than be offset by the direct knowledge obtained of all types of machines, and it is certain that the California Highway Commission will have more accurate data as to the cost of work than they have at present, together with a proper method of providing for the replacement of worn out tools.

TABLE VI (3.7)

Depreciation, Upkeep, Interest, Storage, Insurance

	Rate per Cent per Mile of Work
Road rollers	2.4
Mixers	6.
Finishing machines	7.
Sectional storage bins	7.
Special storage bins (charge full cost)	
Clamshell crane	4.
Stiff leg derrick	4.
Pumps	6.
Pipe lines	6.
Iron stakes	15.
Steel forms	12.
Ford cars	16.
Canvas	10.
Wheelbarrows	10.
Locomotive and cars	6.
Track	2.
Batch boxes	10.
Concrete roller	20.
Strike off board (Tamper & Templates) charge full cost	
Wagon loaders	7.
Camp equipment	8.
Small tools, hose, etc.	16.

	Rate per Cent Per Day Used
Wagons	1/2
Wheel and Fresno scrapers	1/2
Graders—road and elevating	1/2
Plows	1/2
Steam shovel	1/2
Steam drill	1/2
Compressor	1/2
Tractors	1/2

(The job used as a basis for above table is given as a season's work of six miles of 18-foot pavement.)

Items of Equipment	Economical Length of Life	Annual Deprecia-tion	Annual Shop Repairs	Annual Field Repairs	Storage and Incidentals	Insurance and Taxes	Total Annual Chg. % of Initial Investment
	Years	%	%	%	%	%	%
Auto-crane	5	15	6	5	3½	2	31½
Auto-truck	3	25	20	20	3½	2	70½
Auto-trailer	5	15	6	5	3½	2	31½
Backfiller, power	4	18¾	6	7	3½	2	37¼
Ballast spreader	8	9½	6	4	3½	2	25
Boiler, upright	8	9½	20	5	3½	2	40
Boiler, locomotive	8	9½	15	5	3½	2	35
Bucket, clam shell	4	18¾	15	6	3½	2	45¼
Bucket, orange-peel	4	18¾	25	6	3½	2	55¼
Bucket, drag-line	4	18¾	12	3	3½	2	39¼
Cars, steel dump	6	12½	8	4	3½	2	30
Cars, wood dump	5	15	7	3	3½	2	30½
Cars, flat	8	9½	4	3	3½	2	22
Cars, hopper	5	15	8	3	3½	2	31½
Compressor, steam	7	10¾	6	3	3½	2	25¼
Compressor, gasoline	4	18¾	6	7	3½	2	37¼
Compressor, electric	6	12½	3	3	3½	2	24
Concrete chutes	2	37½	15	15	3½	2	73
Conveyor, belt	2	37½	7	6	3½	2	56
Conveyor, bucket	2	37½	10	6	3½	2	59
Crusher, rock	6	12½	5	3	3½	2	26
Derrick, wood	5	15	4	4	3½	2	28½
Derrick, steel	10	7½	4	3	3½	2	20
Dragline, steam	6	12½	9	8	3½	2	35
Dragline, gasoline	4	18¾	10	10	3½	2	44¼
Dragline, electric	8	9½	7	7	3½	2	29
Drill, tunnel carriage	5	15	8	8	3½	2	36½
Drill, traction well	6	12½	7	10	3½	2	35
Drill, tripod	4	18¾	7	10	3½	2	41¼
Drill, jack hammer	4	18¾	7	6	3½	2	37¼
Engine, gas	6	12½	8	8	3½	2	34
Engine, steam	10	7½	5	5	3½	2	23
Excavator, cableway	6	12½	4	12	3½	2	34
Excavator, Keystone	5	15	8	4	3½	2	32½
Excavator, trench	5	15	8	6	3½	2	34½
Forms, steel concrete	2	37½	20	20	3½	2	83
Graders, common road	4	18¾	12	6	3½	2	42¼
Graders, elevating	4	18¾	15	7	3½	2	46½
Hoist, steam	10	7½	6	4	3½	2	23
Hoist, gasoline	6	12½	7	8	3½	2	33
Hoist, electric	8	9½	5	3	3½	2	23
Locomotive, Indus. steam	9	8½	6	4	3½	2	24
Locomotive, Indus. gas	4	18¾	13	10	3½	2	47¼
Locomotive, Indus. battery	4	18¾	15	4	3½	2	43¼
Locomotive, Standard gage	10	7½	6	4	3½	2	23
Locomotive, crane, steam	8	9½	7	8	3½	2	30
Locomotive, crane, electric	8	9½	6	4	3½	2	25
Mixer, steam	5	15	12	4	3½	2	36½
Mixer, gasoline	4	18¾	13	8	3½	2	45¼
Mixer, electric	6	12½	12	4	3½	2	34
Mixer, paving steam	5	15	13	4	3½	2	37½
Mixer, paving gas	3	25	16	9	3½	2	55½
Motors	6	12½	6	4	3½	2	28
Pile driver, steam	8	9½	7	5	3½	2	27
Pile driver, track	10	7½	5	3	3½	2	21
Pile hammer, steam	7	10¾	7	3	3½	2	26¼
Pipe, galvanized	3	25	5	6	3½	2	41½
Plows	3	25	15	10	3½	2	55½
Pneumatic concrete mach.	4	18¾	20	8	3½	2	52¼
Pump, centrifugal	8	9½	6	4	3½	2	25
Pump, piston	6	12½	7	5	3½	2	30
Pump, pulsometer	8	9½	2	4	3½	2	21
Pump, Emerson	8	9½	2	4	3½	2	21
Rails	8	9½	5	3	3½	2	23
Riveter, air	5	15	8	4	3½	2	32½
Rock channeler	6	12½	7	8	3½	2	33
Roller, steam road	10	7½	5	3	3½	2	21
Saw rigs	4	18¾	10	15	3½	2	49¼

Items of Equipment	Economical Length of Life	Annual Deprecia-tion	Annual Shop Repairs	Annual Field Repairs	Storage and Incidentals	Insurance and Taxes	Total Annual Chg. % of Initial Investment
	Years	%	%	%	%	%	%
Scraper, wheel	3	24	8	4	3½	2	42½
Scraper, slip	1	75	25	10	3½	2	115½
Scraper, fresno	2	37½	25	15	3½	2	83
Shovel, steam	6	12½	7	6	3½	2	31
Shovel, gasoline	4	18¾	9	7	3½	2	40¼
Shovel, electric	7	10¾	6	5	3½	2	27¼
Switches, fabricated	3	25	3	3	3½	2	36½
Tower, steel hoist	7	10¾	3	4	3½	2	23¼
Tractor, wheel gas	6	12½	9	5	3½	2	32
Tractor, caterpillar	5	15	15	10	3½	2	45½
Wagons, dump	4	18¾	17	3	3½	2	44¼
Wagons, hauling	4	18¾	12	3	3½	2	39¼
Wagon loaders, power	5	15	10	6	3½	2	36½

PART II

4. SUBGRADES

Adobe and Clay Subgrades 4.1

The heavy adobe and clay subsoils of California are one of the most prolific sources of road failure today in this State.

Failures on the State System

The most notable of the earlier failures on the State Highway System, partly due to heavy adobe subsoils, were those sections on the coast highway north of Los Angeles in what is known as the Calabasas and Conejo Grade areas. These sections consisted of a lean 1:2½:5 concrete, four inches in thickness, the slab being laid directly upon the adobe subgrade. It has been stated that a sand cushion between the adobe and concrete was used in at least one instance as an experiment.

These road sections, completed in 1914 and 1915, showed signs of early distress. The characteristic longitudinal cracks appeared in the slabs and these gradually multiplied and widened until many of the slabs were mere irregular segments of broken concrete with openings varying from two inches to four inches in width.

Efforts to repair the slabs consisted of breaking out and widening the long lines of parallel jagged breaks and filling with new concrete. The results were unsatisfactory and the sections, while not immediately disintegrating under traffic, were unsightly and rough and considered as initial failure areas. Subsequently, initial failures of more or less severity occurred in other sections of the State, due to the same cause.

Sections of the State roads laid on the adobe soils in Alameda, Sonoma, Solano and Contra Costa Counties followed in the wake of the Calabasas failure. The majority of these sections showed signs of distress and failure soon after they were opened up to traffic. By numerous replacements and expensive maintenance, the failure areas have been kept from complete dissolution, but, in general, although the average age of the pavements in question is about 4½ years, many of the sections are in a condition of premature decay, with but a short span of life before the necessary reconstruction.

Among the later failures, from the same cause and in the face of all those preceding, are sections in Yolo, San Luis Obispo, Santa Barbara, Colusa, Glenn, and again in Alameda and Sonoma Counties. These are among the most spectacular failures in the State. Some of these sections were completed as late as 1919, approximately five years after the initial failures in the Calabasas and Conejo Grade areas.

Such is the brief but destructive history of the adobe and heavy clay subsoils on the State Highway system. Of the two soils adobe predominates to a marked degree, and due to its properties of swelling or expanding when absorbing moisture, followed by shrinking or contracting as the moisture evaporates, it is one of the most treacherous and difficult of subsoils to handle in road construction. Adobe apparently predominates in California over other states of the western slope. Its ravages in this State have strewn both the State Highway and many of the individual county road systems with partial or complete road failures.

In the tabulation under chapter 5.02 hereinafter, the high percentage of failures on adobe subgrades is shown. While it is an open question in some instances as to whether poor concrete coupled with heavy traffic or adobe subgrade is the principal cause of the failure, there can be no doubt under any condition that adobe has been a contributing and probably the MAJOR cause in every instance. The summary is valuable in that it gives a general idea of the distressed concrete areas on adobe and heavy clay subsoils irrespective of traffic conditions, weakness of design or integrity of the construction work.

It is of interest to note that the sum of $2,730,600.00 has been expended by the California Highway Commission in the construction of four-inch concrete roads on bad adobe and similar subgrades, where partial and complete failure has already taken place. During the long period over which this expenditure was taking place, no comprehensive investigation, research or experimentation was being made to determine a solution for this particular problem, although early failures must have been of grave concern.

Some scattered and minor attempts at "adobe-proof" construction were attempted in a number of sections, but these lacked the initiative and support of concerted organization action and are therefore not classed as conclusive or comprehensive. They were too limited in extent and entirely lacked comparative methods for guidance, and are therefore of relative value only.

Reconstruction of portions of adobe failure areas has already commenced and more must follow each year, and many miles of the State Highway system in adobe sections remain to be built. Failure to carry out adequate investigation and experimentation will prove as costly in the future as it has in the past, and it is apparent that any expenditure in this research will prove both wise and profitable and no doubt lead to a practical and probably economical solution of the problem.

An examination of adobe subsoils and distressed pavements on the State Highway system leads to certain conclusions with respect to the peculiarities of this type of soil, its action under varying moisture content, and the probable cause of rupture of road slabs viewed from theoretical considerations and practical field observations.

One of the most noticeable features of adobe subsoils is the almost universal tendency to crack a concrete sidewalk or road slab longitudinally. This often occurs along the center line of pavement or within the middle third area. Theoretically, the center longitudinal cracking might be explained as follows:

Case I: A concrete road slab rests on a well rolled and compacted semi-dry adobe subgrade. During the rainy season the side ditches of a low fill section flow full. Horizontal capillarity causes gradual movement of moisture from the side ditches toward the center of fill. At the same time vertical capillarity results in rapid upward movement in heavy soils, moistening the entire subgrade uniformly under the concrete road slab. This uniform moisture content causes uniform swelling of the adobe subsoil. Consequently it is fair to assume that uniform pressure is exerted on the bottom of the concrete slab over the entire width of span.

If we assume reactions due to the weight of the concrete slab plus the frictional resistance due to earth or rock shoulders and consider a uniform load on the slab due to uniform adobe soil pressure, considering simple beam action, the point of maximum moment would be at the center of the slab while the maximum sheer would be at the two reactions. In this case, the bending moment would govern and the slab would rupture at the center of the span, which is just what occurs in practice in a large percentage of initial adobe failures. The weakness of the above theory is found in assumed uniform moisture content and uniform pressure, but more particularly in possible reactions due to slab weight and friction of shoulders. It is, of course, apparent that if reactions are considered as due to the weight of slab alone, the uniform pressure of the adobe soil would probably lift the entire segment of concrete, causing transverse rather than longitudinal cracks.

Case II: In connection with the theory of moisture movement in soils, recent Government tests (Public Roads, Vol. 3, No. 28) have demonstrated somewhat conclusively that vertical capillarity is, in general, more rapid than horizontal capillarity in heavy soils. Under such a condition Case No. 1 fails. Due to the more rapid action of vertical over horizontal capillary water, unequal moisture content of subgrade under slab would result, and in consequence the subgrade pressure on the slab at the sides would occur in advance of the middle third section. If this hypothesis is true, the force exerted by the earth pressure on short sections three or four feet from each edge of pavement in advance of the middle section, would

account for the rupture of the concrete along the shoulders, and that this might be the cause of center cracking is possible because of the earlier expansion at the sides cracking the concrete from below by shoulder heaving followed by center heaving and cracking, as the capillary water produces moisture condition under the entire width of slab. In practice it is common to find both shoulder and center line longitudinal breaks in the same slab.

The two cases above are mere theoretical guesses and are advanced for the purpose of bringing out discussion on the California problem.

From a practical field study of the adobe subgrade problem it is the contention of the writers that the cause of wide longitudinal cracks a few feet inside the dirt shoulders on fill sections is invariably due to settlement of the shoulders and consequent cantilever action of the unsupported overhanging slab which naturally fails, through bending, due to the fact that the thin 4-inch or 5-inch road slab of plain concrete was never designed to act as a true cantilever carrying heavy truck concentrations.

When considering both cut and fill sections and disregarding settlement of grade, probably the principal cause of slab failure along the shoulders rather than at the center can be attributed, from a practical standpoint, to a more rapid drying out of the adobe subgrade along the pavement edges than at the center under the slab. In consequence, the adobe shrinks at the shoulders and for a distance of three or four feet under the slab from both edges, while the moisture under the center of the slab remains more uniform, due to remoteness of center of adobe mass from the exposed shoulder areas and also the protection afforded at center by the concrete "roof." The uniform moisture content at center of mass precludes change of volume and therefore the subgrade at the center neither expands nor contracts to an appreciable degree. Hence, with a constant middle area of subgrade and a changing shoulder volume, the outside portions of roadway are suspended and without support, while the center or middle third section rests on the natural grade. The outer edges naturally break down under loading.

While the action of adobe under varying moisture conditions is well known to California road engineers, a few simple sketches will illustrate more clearly just how the destructive forces work. The conditions depicted on Diagram No. 1, attached, are not exaggerated and may be seen in many sections of the State after the rainy season.

In order to show in simple diagrammatic form the combined destructive action of both adobe subsoils and traffic, Diagram No. 2 covers the various conditions discussed here. In this connection, it may be pertinent to state that while traffic completes the destruction of a suspended or broken concrete slab, adobe subsoils **will cause the initial failure of a concrete highway without a single wheel load having passed over the pavement.**

SUGGESTED SOLUTIONS OF ADOBE PROBLEM

Among the numerous suggestions for combatting the destructive action of adobe subsoils are the following:

1. Chemical treatment of the soil in advance of construction.
2. Structural methods such as cut-off walls at pavement edge; impervious shoulders and berms.
3. Incorporation of shale, gravel, rock, sand or other granular material into adobe subgrade.
4. Laying a heavy Telford Base or a sub-base of gravel or macadam and completing in a manner similar to water bound macadam roads.
5. Increasing thickness of concrete slab to a minimum of eight inches at crown.
6. Reinforcing concrete road slabs.

Taking up these suggestions in their numerical order:

1. The chemical treatment of adobe soils offers a scientific method of solution. It is a common practice in California to apply lime in varying quantities per acre to adobe in order

to reduce soil acidity and make the soil mellow, friable and easier to work. Chemical treatment offers great possibilities. The weakness undoubtedly lies in the length of time the chemical agent will remain active after applying and the practicability of additional applications to the subgrade after a pavement is once laid.

2. Mechanical methods such as cut-off walls and sealed berms and shoulders offer some possibilities. If the moisture content of an adobe subsoil can be kept uniform by these methods, the section so protected will enjoy immunity from the alternating expansion and shrinking of the soil and thus vertical and horizontal movement will be eliminated.

Practically, it is almost impossible to obtain such a uniformity of moisture either by sealed berms or shoulders or cut-off walls. The latter may cut off surface water and prevent it from working under the edges of the concrete slab, and the oiled dirt or oiled macadam shoulder may result temporarily in an impervious area between the pavement edge and the slope of the cut or fill section; but in the winter months, with side ditches flowing full for days at a time, absorption and capillarity working from the sides and lower areas will soon accomplish that which sealed berms and cut-off walls were constructed to prevent.

The writers have removed pavements covering the entire width of street between curbs and known as impervious areas, and found adobe and clay soils moist and plastic in the middle of summer, thus demonstrating that moisture was absorbed during the winter, even where an impervious paved surface existed, and was persistently retained by the fine grained subsoil long after the rainy season was over. In this connection, however, it must be stated that the sidewalk areas adjacent were not impervious, being paved only in the center.

In practice, it is a physical impossibility to maintain a sealed dirt shoulder. The first heavy truck turning out from a paved road onto an oiled dirt shoulder, especially in the winter months, accomplishes its ruin. Sand oiled to depths of six to twelve inches often provides a wavy corrugated, impervious shoulder that does not cut up readily under traffic. Oiled adobe however, is another problem. Oil macadam shoulders, when placed contiguous to a concrete road carrying much traffic, have proven inadequate and expensive and are being rapidly abandoned. Continual maintenance may keep such shoulders in passable shape, but the history of such shoulders in this State is one of early disintegration and destruction. On a wide concrete road where traffic would not be forced to utilize the shoulders except at intervals, such shoulders would be more satisfactory and effective.

3. The incorporation of shale, gravel, rock, sand and other material into an adobe subgrade by harrowing and working the soil, has given a measure of good success in preventing longitudinal fractures of concrete slabs. The undersigned have used this method on numerous occasions and found it on an average 90 per cent effective. Some standard practice should, however, be evolved and the material worked to specified depths in every instance. In addition, not less than 50 per cent and preferably 60 per cent to 75 per cent of the adobe subgrade should be excavated and replaced with the granular material available, the whole worked and reworked into the adobe subsoil until a complete homogeneity is secured. As about any class of inferior gravel, soft sandstone, hard shale or other material unsuited for concrete work or macadamizing is satisfactory for this subgrade adulteration, the method offers one of the lowest cost and most practical means of combatting adobe subsoils.

In this connection it is pertinent to state that the sand-clay roads of the Eastern and Southern States are but replicas of what may be accomplished with adobe if sand alone in sufficient quantity is worked into the surface.

Monterey County, in California, by the application of this same principle to the adobe of the Salinas Valley, produced winter roads that would have otherwise been impassable after the first rains. Such a road surface must naturally prove a most desirable subgrade for concrete.

4. This method is not unknown; the Telford base is very effective, and wherever an old gravel or macadam road existed over adobe subsoil prior to replacing with a concrete pavement, the results obtained have been uniformly good. The exception is usually where the road metal has been very thin or where it has been completely excavated or covered up in order to correct the existing gradients.

5. Increased thickness of concrete at the crown is certainly reducing longitudinal cracks in many sections of the country. Comparison of roads in other states somewhat confirms the soundness of the method. Just what the effect might be on heavy adobe soils, we are unable to say; as experience and observation demonstrate that concrete slabs laid on adobe soils rupture along the sides as well as at the center, it would appear that the greater moment of resistance due to increased thickness of slab is needed not only at the crown but at the one-third points as well.

Here again, test roads of varying thickness should be built over bad adobe subsoils and the results carefully noted and recorded.

6. This method is undoubtedly the most certain and effective. Its weakness lies in probable prohibitive cost. Undoubtedly, a concrete road slab can be so heavily reinforced with steel and built so thick that it will be able to withstand the action of the worst and most destructive type of adobe subsoil. The question then becomes one of economics and it is a matter of grave doubt as to whether any community is justified in designing and building such a roadway in the light of the very meagre research investigation and experiments that have been made in California to date.

Recommendations

It would be our suggestion that the subject matter of this portion of the report relative to adobe subsoils be carefully considered by your association. We believe the problem is big enough to require both Federal and State investigation, research and experimentation. That other sections of the country are awakening to the economic loss due to types of subsoil, saturation, low bearing value and other subgrade weaknesses, is evidenced by the recent investigation of highway subgrades undertaken by the Federal Highway Council and already referred to in another section of this report.

In any case, immediate precautionary measures and special construction of slab, together with adulteration of subgrade should be adopted by the Highway Commission, thus utilizing every reasonable means for checking the economic loss to the people of the State through adobe subgrade road failures.

Drainage of Heavy Subsoils 4.2

To one of the older professors of highway engineering is attributed the following statement, viz:

> "There are three, and only three, important fundamental principles to remember in the design and construction of any type of road. The first is drainage; the second, drainage; the third, drainage."

That this is not overdrawn is known to every experienced road engineer.

It is well known that saturated soils are notoriously unstable for any type of foundation; that the bearing value of most soils will decrease as the amount of moisture within the mass increases. The problem, naturally, is to remove the cause by eliminating the source and draining the body. Unfortunately, this is not always possible; therefore, in the criticism of any road section that has apparently failed through lack of drainage, all of the facts are imperative if a just and unbiased decision is to be rendered.

On various sections of State Highway are found evidences of road failure due apparently to the absence of proper drainage ditches, cut-off walls, rock and tile drains; also many low

fills are subjected to overflow and saturation by the elements and by irrigation water. As a general statement, culverts are adequate and properly located. The principal failures can be traced in nearly every instance to adobe and heavy clay soils, and in this respect the narrow concrete road sections aid in the saturation of the grade and consequent road failure due to the cutting up of shoulders under traffic. The deep furrows produced by a truck or auto floundering around on a boggy shoulder, or the ordinary wheel-ruts from turn-out travel, spell disaster in one form or another. The remedy for this condition is discussed under "shoulders and berms."

In thorough cuts and on side-hill cut-and-fill areas, particularly where clay, adobe, soft serpentine and weather rock in various stages of decomposition predominate, the installation of rock or tile drains at the toe of each slope in the former and at the side-hill gutter line in the latter, has a most beneficial effect in cutting off much water that now finds its way under the pavement to its detriment.

The writers have under-drained heavy clay through cuts that were a mass of boggy subsoil by installing V-shaped rock drains across the entire road-bed and continuous through the cut. With a proper gradient and outlet where the cut slopes run out, the drainage is free and more or less effective. Again, rock drains 2½ to 3 feet in depth were also installed in the gutter line on the cutside of heavy saturated adobe cut-and-fill sections, with excellent results. However, this method of drainage acted more as a cut-off or intercepting drain to keep gravity water moving to points of disposal, thus reducing saturation of subsoil.

In dealing with heavy clays, decomposed serpentine and similar rocks, adobe, etc., the mechanical means of drainage are not always effective. The construction of side ditches or the installation of rock or tile drains, while acting admirably as intercepters, are of questionable value in freeing heavy soils of water that is not subject to gravity flow but is taken up and retained by vertical and horizontal capillarity. Tile or rock drains serve their purpose when they intercept and carry off water from slopes and shoulders, but when these self-same drains are flowing full for days at a time during the rainy season, it is apparent how, and why, some subsoils under a pavement take up and retain moisture.

Sand, decomposed granite, gravel and similar types of subgrades, are ideal road-beds. Due to the per cent of voids and large pores, these soils free themselves of water by gravitation. On the other hand, soils with fine pores such as adobe and clay soils, take up and retain water by capillarity. Likewise, water taken up by these latter soils is not removed by the action of gravity but by this self-same capillarity, hence the extreme difficulty in properly draining heavy soils.

Fill sections are presumably properly drained when the grade elevation is well above the low surrounding ground, proper culverts installed, and adequate side ditches on gradients above one-half of one per cent are constructed. In practice, however, such a section built of clay or adobe is subject to the same saturation evils that are found in cut sections. Side ditches flowing full during the heavy winter months, allow the fill to take up and retain moisture throughout its entire cross-section, depending upon the severity of the season. Cut up shoulder areas complete the work of the elements.

Viewing the whole question in the light of a practical solution it would appear that a more liberal and extensive use of V-shaped under-drains, open-throat rock drains, combined rock and tile drains, short cut-off walls, and similar structures, would give far-reaching results and the additional expense be fully warranted in view of California experience. As to a permanent solution of the heavy subsoil drainage problem, we believe that experiments on a broad scale, under actual service conditions and of varied nature, should be conducted over a considerable period of time, if concrete results are to be obtained. This subject could well be taken up in conjunction with the investigations now being made by the Federal Highway

Council (Akron, Ohio, Meeting, Engineer's News Record, Oct. 21, 1920). As we view the subject of subsoil drainage, control of capillary water and uniform moisture content, conditions in different states must naturally vary dependent upon the types and classes of soils encountered. Therefore, exhaustive investigations and experimentation in the various states of the Union with attendant correlative data should prove of great value to every individual state in the matter of future road design.

Uniform Policy Recommended for Settlement of Heavy Fills 4.3

The lack of a uniform policy in the various divisions of the State Highway Department in the matter of proper settlement of heavy fills previous to paving, has often been a source of criticism. As an example: one division with proper foresight and regard for the safety of the concrete pavement will require all fill sections over two feet in height to be thoroughly puddled with water by ponding—a most efficient and successful method. Another division will omit the heavier fill sections from paving altogether for a period of one or two years, allowing the elements to settle the grade. Paving temporarily with gravel or macadam is resorted to in order not to discommode traffic. On high fill sections this is more economical than ponding and of greater efficiency. Some divisions have paved over heavy fill sections without adopting either method.

Where the two first methods have been adopted (with the exception of some mountain grades) very little settlement or loss of concrete pavement has occurred. In the case of the last mentioned method, a large amount of concrete pavement has been lost and replacements have been frequent and costly.

It is our suggestion that in order to avoid settlements of fill sections in future, accompanied by the loss of the concrete pavement over such fill areas, **the State Highway Specifications be modified to cover this point fully and comprehensively in order that the practice throughout the entire State organization may be uniform.**

Flat vs. Crowned Subgrades 4.4

This is a subject closely correlated with pavement cross-sections, therefore of little importance unless the flat subgrade be advanced as an argument in favor of thicker crown sections and on a basis of simpler and more economical construction.

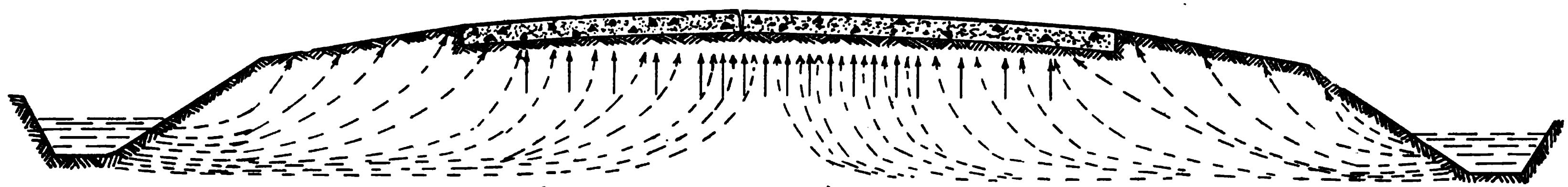
Our experience would lead us to doubt the latter contention which, by the way, is often advanced by the advocates of the flat subgrade.

In California it is the practice of most contractors to take out the finished grade with a subgrade machine operating on the headers. The cost of operating such a machine would be practically the same for either a crowned or a flat subgrade; hence, with scarifying, sprinkling, rolling, and similar charges the same in either case, there is practically no difference in cost. On the other hand, some additional yardage must be moved in cut sections where a flat subgrade is used and this, while minor, would make the flat subgrade more expensive than the crowned section, the whole based on the unit price for yardage.

Naturally, if a concrete road is built thicker at the crown than at the shoulders, the flat subgrade follows as a matter of general practice. Conversely, if a uniform section is constructed, the crown, of necessity, must be taken up by the subgrade. **Therefore, the question of the use of flat or crowned subgrade is governed by the pavement cross-section.** See discussion under the caption, "Should a Concrete Slab Be of Uniform Thickness or Variable Cross-section?"

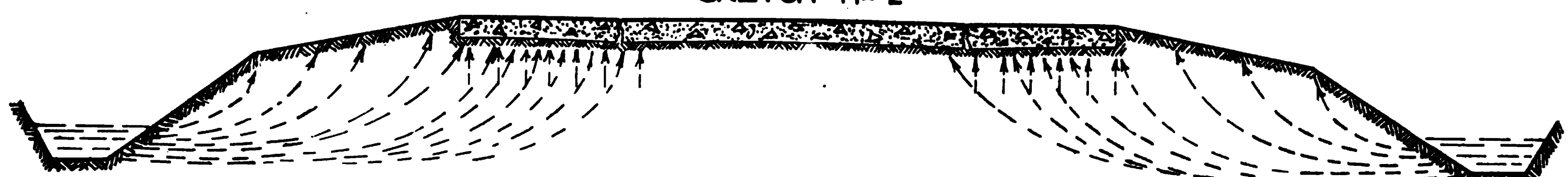
DIAGRAM 1

SKETCH No. 1



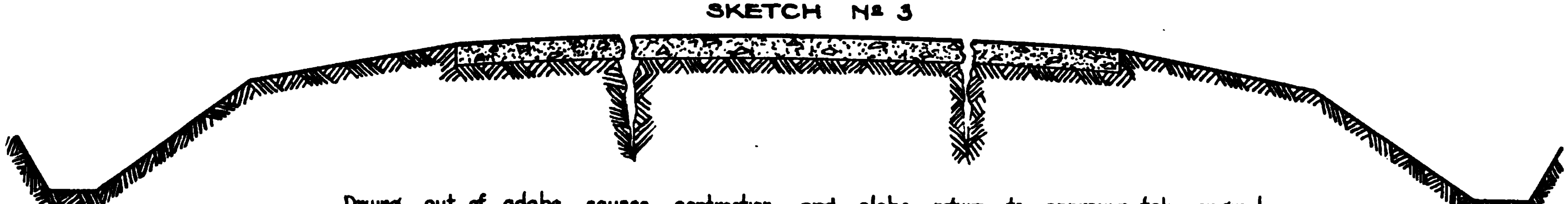
Shows vertical forces acting, due to absorption of moisture. Swelling of adobe ruptures slab at center, producing wide longitudinal cracks, and thrusting slabs above Finished Crown grade. Opening at center allows saturation of subgrade and consequent failure unless immediate repair by maintenance crew.

SKETCH No. 2



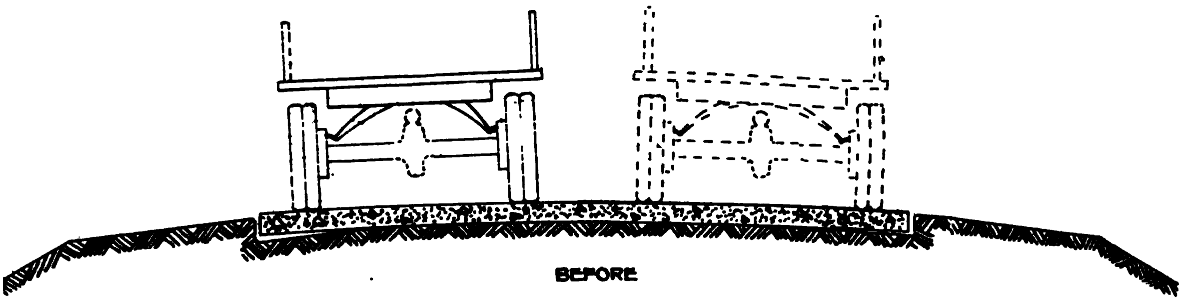
Due to more rapid vertical capillarity, moisture is absorbed faster at sides than center. Forces due to swelling adobe acting at sides in advance of center causes rupture of concrete slab as shown.

SKETCH No. 3



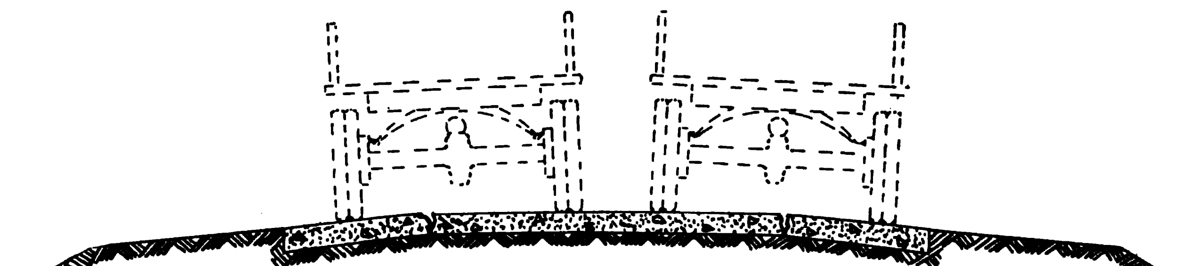
Drying out of adobe causes contraction, and slabs return to approximately original position, fractures widening as subsoil below continues to shrink and develop deep cracks.

DIAGRAM 2



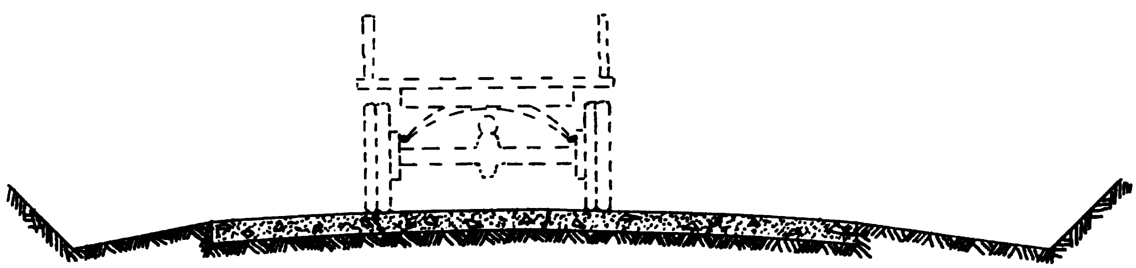
BEFORE

Suspended shoulder slabs due to shrinkage of adobe or settlement of shoulder.



AFTER

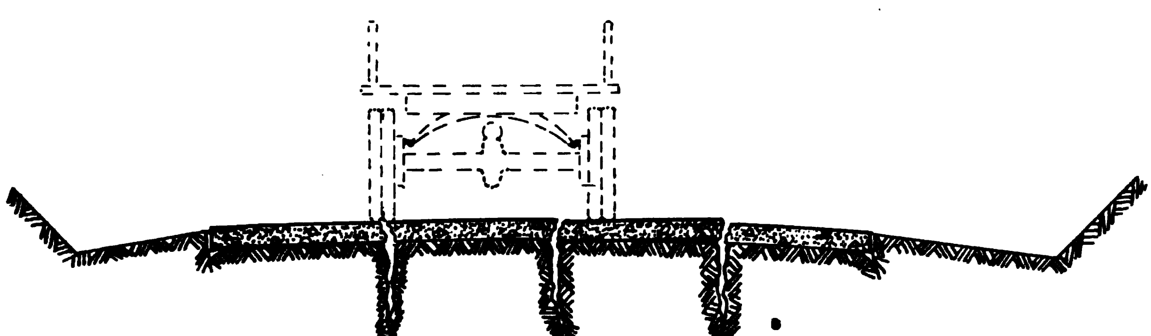
Same suspended shoulder slab showing failure due to heavy wheel loads.



BEFORE

CONCRETE SLAB LAID ON DAMP SUBGRADE

Additional absorption of moisture causes minor fractures enhanced under traffic



AFTER

Shrinkage and cracking of adobe subsoil causes minor fractures to open up into wide longitudinal cracks. Segments displaced and fractured by heavy loads.

5. THICKNESS OF ROAD SLABS

Pavement Failures From Inspection Reports 5.01

Inspection of the State Highway system in the forty-five counties comprising the central and northern sections of California included a careful investigation of 747.5 miles of concrete paved roads.

An effort was made to classify these pavements as good, fair and poor, and in order that a more comprehensive idea may be obtained as to just what this classification means and how the authors were guided in making the same, the definitions used are given below.

Good pavements are those which show no inherent defects; may contain the usual shrinkage (transverse cracks), and if not entirely free from longitudinal cracks and small triangular breaks must contain these at such intervals and in such dimensions as to affect but little the integrity of the pavement.

Fair pavements, in addition to the above, may contain parallel longitudinal cracks and frequent triangular breaks, providing displacement of slab is not apparent and concrete is not broken down and disintegrating. Minor fine surface cracking without disintegration is allowable.

Poor pavements must show displacement of slab together with breaking down and disintegration of concrete; considerable patching and continuing raveling or bad crushing of shoulder sections with center cracks and settlements.

This more or less arbitrary classification has its value in relation to the other facts developed hereinafter, and, while such classification might vary with the individual, the general percentages of the total graded mileage will not differ greatly in the last analysis.

The following tabulation is the segregation under the three gradings of the 747.5 miles inspected:

	Miles	Per Cent
Good pavements	465.5	62.3
Fair pavements	149.5	20.0
Poor pavements	132.5	17.7
Total	747.5	100.0

Character of Subgrade Under Poor Pavements 5.02

During the field investigation noted in the preceding paragraphs, investigation of subgrade conditions and material was given careful attention.

It is of particular interest to compare the percentage of pavement failure which has occurred on adobe subgrades with that on better foundation material, and the following tabulation covers this information:

	Miles	Per Cent
Failure (poor) pavement on adobe	80.5	60.7
Failure (poor) pavement on loam or sandy loam	52.0	39.3
Total	132.5	100.0

Traffic Conditions in Zones of Pavement Failure 5.03

It is of further interest in arriving at any conclusions as to the principal factors contributing to pavement failure to examine the traffic conditions at those points where distressed pavements are found.

Of the total of poor pavement already classified, the amounts in the tabulation following show the mileage and per cent subject to various traffic conditions:

	Miles	Per Cent
Under heavy traffic	54.00	40.8
Under medium traffic	74.00	55.8
Under light traffic	4.50	3.4
Total	132.50	100.0

Relation of the Age of Pavement to Areas of Failure 5.04

It is also of interest to note the relation existing between the age of pavements and failure areas. The following tabulation shows the total miles of pavement constructed each year in the central and northern counties; the total miles of each construction period which now show failure; the percentage of each of the latter to the total failure area; and the percentage of the amount constructed each year which now shows failure.

Year Constructed	Concrete Pav. Constructed	Concrete Pavement Now in Poor Condition		
	Miles	Miles	% of Total in Poor Condition	% of Mi. Const. During Year
1914	136.9	28.6	21.6	20.9
1915	165.8	34.1	25.7	20.6
1916	231.2	50.2	37.9	21.7
1917	38.5	2.7	2.0	7.0
1918	44.8	8.6	6.5	19.2
1919	77.7	5.9	4.5	7.6
1920	52.6	2.4	1.8	4.6
Total	747.5	132.5	100.0	

Steel-Bar Reinforcement vs. Plain Concrete Slabs 5.05

The California Highway Commission on September 8, 1920, adopted a general policy of steel-bar reinforcement for all concrete road slabs. It is stated that "because of the rapidly increasing volume and intensity of the traffic over the State Highway, no concrete base shall be laid on any State Highway a lesser thickness than five inches and all concrete bases are to be reinforced with steel." To quote from the instructions of the Highway Engineer:

> "On all future day labor authorizations and contracts for the construction of concrete bases and for concrete shoulders, the outer edges shall be reinforced by ½-inch square deformed steel bars placed longitudinally along the edges, centered in the depth of the slab, and placed two inches from the outer edges. Such longitudinal bars shall be lapped 12 inches for bond. At intervals not greater than 30 feet the bars shall be butted and not lapped. Transverse reinforcement shall consist of ⅜-inch square deformed steel bars placed transversely on 18-inch centers, such transverse bars being hooked over the longitudinal bars and securely wired thereto."

Apparently the newest policy of the California Highway Commission contemplates universal use of steel-bar reinforcement on all sections of the State Highway, regardless of the type of subsoil encountered.

Few road engineers of experience will question the need or desirability of either a thicker section of concrete or of special steel reinforcement, **or both,** when a road is to be built over a spongy subgrade, heavy adobe or clay subsoils or marshy and boggy areas. It is, however, a grave question, both of economical construction and paving design, as to whether so radical a policy of steel reinforcement, to be used under any and all conditions throughout this State, is not a serious mistake and open to strong criticism. For example, the sand and sandy loam subgrades of the lower section of the San Joaquin Valley afford most excellent foundations for the plain unreinforced concrete slab. This is strongly evidenced by the present condition of the 4-inch 1:2½:5 concrete base on numerous 10-mile sections of State Highway between Bakersfield and Modesto. Some of these sections are from six to seven years old and have been subjected to a steadily increasing traffic from the date of completion. They are giving remarkable service for so thin a section and so lean a mixture. In this connection, probably no more ideal subgrade conditions can be found than the decomposed granite and sandy loam soils of San Diego, San Bernardino, Riverside, Orange and Imperial Counties, and the same

may be said of Tehama, portions of Glenn and Butte County (Oroville district) where the subsoils make ideal rough graded roads, due to the high percentage of gravel, sand, loam and decomposed granite. Placer, Shasta, Siskiyou, Calaveras and other counties in the mountain districts have natural rock or hardpan sections ideal for any type of road construction. Therefore, a study of the soil conditions in different sections of California will convince the average highway engineer of the fallacy of adopting a construction program that specifies costly steel reinforcement in concrete road slabs irrespective of the subsoil conditions in each individual road district. Experience dictates a selection of the respective type of road to fit the conditions of subsoil and drainage, but always with due regard to a standard of minimum thickness of slab or base to meet the requirements of present day motor traffic and probable life of the structure under the ever increasing traffic volume and loadings. On this hypothesis we believe the present policy of the State in adopting a 5-inch reinforced concrete slab for universal application to the California road problem, unsound both from an engineering and economical standpoint.

While mathematical investigation of stresses in road slabs is recognized as faulty in many instances, due to the indeterminate factors surrounding loadings, distributions, varying subgrade reactions and the numerous other conditions which preclude an exact analysis, it is possible to make certain simple calculations which act as a guide to good paving practice.

In connection with steel reinforcement as now proposed by the State Highway Commission, the following statement is credited to the chairman of the commission at a public meeting held in San Francisco in June, 1920, viz:

> "During this last year we have passed a general order requiring every piece of concrete to be reinforced, and the consensus of opinion of our engineers is that the reinforcing of the concrete highway is the equivalent of thickening it at least two inches."

This is not borne out by mathematical analysis or actual laboratory tests.

It is well known to all designing engineers that concrete is high in compressive and low in tensile strength. An average ratio would be about one to seven; therefore the primary object of steel reinforcement in a girder or slab subjected to flexure is to take care of the tensile stresses set up and to distribute the action of the superimposed loading. In the rational design of a slab with proper percentage of steel reinforcement—acting within the limits of its working stress—lies the value and efficiency of modern reinforced concrete construction. In a 5-inch road slab with ⅜-inch bars spaced 18 inches on centers, however, the amount of steel is insufficient to take care of tension in conjunction with direct compression when the road slab acts as a simple beam. On the other hand, subgrade movement or failure may cause the slab to act as a continuous beam or again as a cantilever and the slab requires steel in both top and bottom. Apparently the only function a light steel reinforcement serves in a road slab is to take care of temperature stresses or prevent opening up of cracked sections over adobe and similar soils.

The increase in strength due to adding the light reinforcement described to a plain 5-inch concrete slab, is not marked. Allowing the concrete to take full tension (if the concrete and steel act without the concrete cracking) the moment of resistance due to the light reinforcement is only 271 pounds, while the moment of resistance due to the concrete is 15,000 inch pounds; a difference of approximately 1.8 per cent in favor of the reinforced slab, as shown by the following analysis:

$$K = \frac{h^2 + 2pnd^2}{2dh + 2pnd^2} = \frac{25.875}{35.875} = .721$$

$$\frac{Ec'}{Ec} = \text{Unity} \qquad fc = 300 \# \text{ sq. ''}$$

$$f_c' = \frac{E_c'}{E_c} \quad f_c \frac{Kd}{h\text{-}kd} = 300 \times \frac{2.52}{5\text{-}2.52} = 303 \# \text{ sq. '' compression}$$

$$M = f_c' \frac{bh}{2}\left(2d - \frac{h}{k} - h + \frac{2h^2}{3kd}\right)$$

$$= (7 - 6.93 - 5 + 6.61) = 15{,}271 \text{ inch lbs.}$$

A comparison between plain concrete slabs of 5 and 7-inch thickness respectively, gives the following moments of resistance for a section 12 inches wide:

Using a fiber stress of 300 lbs. per sq. inch $= f_c$

$$M = \frac{KI}{d} = f_c \frac{bh^2}{6} = \begin{cases} \dfrac{300 \times 12 \times 25}{6} = 15{,}000 \text{ Inch lbs.} = 5'' \text{ Slab} \\ \\ \dfrac{300 \times 12 \times 49}{6} = 29{,}400 \text{ Inch lbs.} = 7'' \text{ Slab} \end{cases}$$

or a moment of resistance approximately 96 per cent greater than the 5-inch reinforced slab. By mathematical analysis, therefore, it is shown that a 5-inch concrete slab reinforced with ⅜-inch steel bars 18 inches on centers is not equal in strength to a plain concrete slab seven inches thick, as claimed by the Highway Commission; in fact, the plain slab five inches in thickness is theoretically about as strong as the more costly 5-inch reinforced slab.

We will go further in this analysis and endeavor to check the relative strength of plain and reinforced concrete slabs of equal thickness by recent actual laboratory tests.

In a series of tests made in 1918 and 1919 by the city engineer of Seattle, Washington, on various types of concrete pavement bases and slabs, using a 1:2:3½ concrete mix (1 barrel cement 3½ cubic feet) the following results were attained, viz:

PLAIN CONCRETE SLABS

No. Slab	Age Days	Thick-ness	How Finished	Mixture 1 bbl. = 3½ Cu. Ft. Cement	Load at Failure, lbs.	Average
C 1-1	28	6″	Floated	1:2:3½	7070	
C 2-2	28	6″	Floated	1:2:3½	7450	
C 1-2	28	6″	Rolled, 35 # R	1:2:3½	8980	
C 2-1	28	6″	Rolled, 35 # R	1:2:3½	9600	8648 lbs.
C 8-1	28	6″	Tamped	1:2:3½	9260	
C 8-2	28	6″	Tamped	1:2:3½	9530	
C 3-1	28	7¾″	Rolled	1:2:3½	18790	18790 lbs.

REINFORCED CONCRETE SLABS

Wire Mesh

No. Slab	Age	Thick-ness	How Finished	Mixture	Load at Failure	Average
C 6-1	28	6″	....	1:2:3½	11650	10930 lbs.
C 6-2	28	6″	....	1:2:3½	10210	

SUMMARY

Comparing 6″ vs. 7¾″ Plain Specimens

7¾″	=	18790 lbs.
6″	=	8648 lbs.
Difference	=	10142 lbs., or approx. 117% by actual test

Comparing Average of 2 6″ Plain Slabs Rolled, vs. 2 6″ Reinforced Slabs Rolled

6″ R. C. Aver.	=	10930 lbs.
6″ Plain rolled	=	9290 lbs.
Difference	=	1640 lbs. in favor R. C., or approx. 17.7% by actual test

Comparing 1¾″ Additional Plain Concrete Thickness with 45 # Wire Mesh Reinforcement

7¾″ Plain	=	18790 lbs.
6″ Reinf. Concrete	=	10930 lbs.
Difference	=	7860 lbs. = 72%

Therefore, 1¾-inch additional thickness of concrete gives 72 per cent greater strength by actual test.

Apparently these results check the theoretical computations very closely.

In order to confirm the Seattle laboratory tests, your Association authorized its engineers to conduct a series of tests on reinforced concrete road slabs of varying thickness. These tests are now being made under the personal direction of Prof. Charles Derleth, Jr., Dean of the College of Civil Engineering, assisted by Prof. C. T. Wiskocil. The results of these tests are unfortunately not available for this report. They will be made the subject of a brief special report at a later date and forwarded to the Association in due course.

While it is our belief that steel reinforcement as now proposed by the California program adds but little to the effectual resistance of the concrete, when viewed in the light of a suspended slab, a cantilever, or a continuous beam, yet if its function is merely to reduce longitudinal cracks in a concrete road, there is little doubt as to the effectiveness of steel bars. An inspection of some 40 miles of four-inch concrete State Highway in San Luis Obispo and Santa Barbara counties was made by the Engineers of both Auto Clubs, accompanied by the State Division Engineer of this section. Numerous stretches of this road were found badly cracked and shattered. The failure areas are all confined to the heavy adobe subsoil sections; wherever the adobe ends and sand, loam, or gravel subsoil begins, the excellent condition of pavement is particularly noticeable. Some 37,000 lineal feet of pavement was originally reinforced, steel bars ⅜-inch diameter spaced 18 inches on centers, or .068 plain triangular mesh being used. The wire mesh reinforcement has apparently proven of little or no value; slabs reinforced with mesh show myriads of cracks, and in most cases these sections differ but little from the plain concrete sections. With the ⅜-inch steel bar reinforcement, the efficiency of such construction is strikingly apparent. While longitudinal cracking of concrete slabs is not eliminated completely on these bad adobe subsoils, it is controlled in a very marked degree; the cracks are far less frequent and seldom open up in the destructive manner noticeable on adjacent sections that are not reinforced.

At present it is problematical just what the final history of this 37,000 lineal feet of reinforced concrete road will ultimately prove. The present age of the sections is only from one to two years, and any test upon which to base final judgment must necessarily cover a longer period. At present, however, the results cannot be questioned.

The conclusions we have arrived at in the analysis of strength ratios is that wire mesh reinforcement as laid under California Highway Commission specifications is inadequate and ineffective, therefore a useless expense; that ⅜-inch steel bar reinforcement adds but little to the actual strength of a concrete road slab but is effective in reducing and controlling longitudinal cracking; that experience with bar reinforcement in this State, especially with respect to heavy adobe soils, has been very limited and its economy and efficiency not determined conclusively by the test of time; that no extensive comparative tests have been made of treated or adulterated adobe subgrades in conjunction with plain concrete road slabs of varying thickness and that the economy and efficiency of this method should be thoroughly investigated and studied by the construction of actual road tests in the field; that it is uneconomical and questionable engineering practice to specify steel bar or any other type of reinforcement for use under any and every condition of subsoil and subgrade in California, as is now being done by the State Highway Commission, and that,—finally, based on an approximate figure of $2,000.00 per mile for present reinforcement and with a conservative estimate of 500 miles of State Highway to be built or reconstructed over ideal subsoils, hard pan, or rock within the next few years, more than $1,000,000 can be easily expended for unnecessary reinforcement when the same sum expended in actual road construction might in the final analysis mean the completion of much additional road or more properly designed roads on the heavily traveled sections remaining to be paved or in need of reconstruction.

Should a Concrete Slab Be of Uniform Thickness or Variable Cross-Section? 5.06

In connection with flat or crowned subgrades arises the very important question as to whether a concrete road slab should be thicker at the center than at the sides.

The general practice in many states is to build concrete roads with greater thickness at the crown. Most cities, however, still cling to the practice of building pavements of uniform cross-section between curbs and hence on a crowned subgrade. Why there should be any variation in practice is apparently not determined.

Engineers differ somewhat on the relative merits of thicker crown road sections. For example, Professor A. N. Johnson, Dean of the College of Engineering, University of Maryland, advocates the thicker crown section, while Mr. Samuel Whinery, M. Am. Soc. C. E., Consulting Highway Engineer, New York, takes an opposite view. (See Engineering and Contracting, January 2, 1918.) Mr. Arthur H. Dimock, M. Am. Soc. C. E., present City Engineer of Seattle, Washington, favors the section of uniform cross-section. "Engineering & Contracting," in an editorial, December 5, 1917, advances the opinion that the practice of making concrete pavements thicker at the crown than at the edges is erroneous. Numerous road engineers voice similar views.

The present practice in California is to crown the subgrade and build the concrete pavement of equal or uniform thickness at crown and shoulder.

Irrespective of the practice in other States, it is our belief that the California method is structurally sound, and, until more convincing data and practical demonstrations of the superior value of the thicker crown section are brought to light by investigation, this question may well be left in its present status in this State.

As to our own conclusions:—taking as an example a uniform 6-inch concrete slab vs. a slab 7 inches thick at center and 5 inches at sides, we believe the uniform 6-inch slab structurally superior to the 5-inch shoulder section. The addition of one inch of concrete at the edges increases the moment of resistance nearly 45 per cent at the point of greatest weakness, gives greater inertia and strengthens a section of road where wheel concentrations are heaviest, due to restricted distribution of loading at the pavement edges.

As triangular breaks are one of the most prolific causes of maintenance in California and always occur at the shoulders; also as fully 75 per cent of all failures on the California High-

way system are found along the sides rather than at the center of the road, it seems obvious that any additional strength of slab secured at the pavement edges and sides is an added factor of safety and hence desirable. A chain is only as strong as its weakest link. Added strength given to a slab at the center of the roadway, therefore, seems misplaced in view of the greater volume of traffic on the sides. The theory of cantilever or beam action advanced in advocacy of thicker crown sections is hardly tenable in view of the indeterminate factors surrounding such action. Unreinforced cantilevers or beams of so shallow a depth as 6 inches or 7 inches, depending on a yielding subgrade for end support and of uncertain or unknown span length, allow of no particular mathematical deductions that will definitely substantiate the value of so-called beam or cantilever action.

Except in special cases of bad adobe or heavy clay subgrades, where slabs tend to fracture along the center line from subsoil pressure or swelling, we believe concrete road slabs should be of equal strength over entire roadway, hence of uniform cross-section.

Importance of Longitudinal Cracks in Concrete 5.07

Rectangular or transverse cracks in concrete pavements can be largely eliminated or controlled by expansion joints. Longitudinal cracks are apparently becoming of less importance with a liberal use of steel bar reinforcement, but there are innumerable instances where steel reinforcement is not warranted or justified over an entire road section **in order to avoid the possibility of a few longitudinal cracks.** On adobe and clay subsoils, as already discussed, there can be little argument as to the desirability and efficiency of the use of reinforcement. But to spend $2,000.00 or more per mile in "**anticipation of longitudinal cracks**" or subsoils where experience has shown their rare occurrence, is wasteful and unjustified.

The importance of longitudinal cracks varies with the subsoil. On adobe, clay or poorly drained loams, the cracks take on a degree of importance that often spells failure for the entire pavement area. On the better types of subsoil, even with so thin a section as 4 inches, longitudinal cracks are either entirely absent or so infrequent or minor as to be of practically no importance.

Longitudinal cracks are so infrequent in the thicker and heavier concrete roads of adjacent states as to be most marked. It is to be hoped that the future design and construction of concrete roads in California will be such as practically to eliminate permanently and completely all unsightly longitudinal cracking.

Minimum Thickness of Plain Concrete Road Slabs for California Conditions 5.08

It has been frequently remarked that California has the "narrowest, thinnest and leanest" concrete roads in the United States. Comparison with other states confirms this statement. For many years subsequent to 1913, the 4-inch, 1 :2½ :5 concrete road, 15 feet in width, was recognized as the State Highway standard.

While it can be proven that the average 4-inch concrete road is unsound, both structurally and economically, yet up to 1917 this 4-inch road was giving good service and the percentage of failures, generally speaking, were no greater than those experienced by municipalities all over the country on all classes of pavements. The rapid increase in motor traffic and the steadily increasing wheel-load concentrations during the past few years, however, has caused rapid deterioration of a considerable percentage of the 4-inch road and in consequence surfacing with plant-mixed asphalts, "double decking" with 4 inches of additional concrete, reinforced with steel bars, and other heroic treatment has been necessary in order to save the older bases from total destruction. This is more or less general in the districts contiguous to thickly populated areas.

The table in the opening chapter of this subject shows the present condition of the paved State Highways in Northern California. It will be noted that the table confirms the statement relative to failures contiguous to populous centers, viz.: 96.6 per cent are in districts subjected

to medium and heavy traffic. It also shows the importance of subsoil formations and the large problem California must face to save its roads from destruction by other than traffic and load considerations. Of the sections of paved road inspected in Northern and Central California only, varying in age from 7 years to less than 1 year and aggregating 747.5 miles, approximately 132.5 miles are in a condition of partial or almost complete failure and many additional miles have been or are being surfaced with asphalt or otherwise repaired and reconstructed. The largest per cent of failures is found to occur on the adobe and clay subgrades. The high percentage of failures on loam or sandy loam subgrades is directly traceable to heavy traffic and overloads on the thin 4-inch concrete road section.

Of the 615 miles of good and fair pavements in Northern California, with few exceptions, practically all are laid on decomposed granite, sand, sandy loam, gravel or other type of recognized stable, well-drained subsoils.

A careful study of the type, age, and traffic conditions, coupled with a personal inspection of the individual road units throughout the State, can lead to but one conclusion, viz.: The concrete roads on all of the main trunk lines of the State system must be increased in thickness over the old 4-inch standard, in order to provide for present and future traffic. This thin section has served its purpose and must now be relegated to the past, and that the State Highway Commission has recognized this important point is evidenced by the very recent ruling already discussed, whereby 5 inches is made the minimum depth of concrete base, the same being reinforced with steel bars. By what practical method of mathematical or financial process this stated minimum reinforced section for "**all roads on the State system irrespective of subsoils, drainage, traffic or other considerations**" is arrived at, we are unable to determine.

The question as to just what thickness of concrete slab is needed to meet the present and possible future needs of traffic is a very broad one. Drainage, subsoils, traffic and kindred other factors enter into the design and these must be backed up with prevailing practice and by long experience in road construction in the intelligent design of a road that may be expected to live out its allotted span of life. We believe it is universally conceded that with our present knowledge, a concrete road slab or any other type of so-called permanent pavement, is not possible of exact mathematical analysis, hence we must resort to practical methods in place of theoretical computations in attacking the problem, utilizing the latter merely as a guide to rational design. A simple demonstration of the value of mathematical analysis in connection with rational slab design is given under the caption "Steel Bar Reinforcement vs. Plain Concrete." That the strength of a plain concrete slab does not increase in a direct ratio with its thickness but that the moment of resistance increases as the square of the depth; also that the resisting moment is dependent on the extreme fiber stress and section modulus for a slab or beam of unit width, is well known; hence if we desire to know the increased resisting power of an 8-inch plain concrete section when compared with a 4-inch slab, by straight analysis we find the 8-inch slab in its ability to resist rupture is 300 per cent stronger than the 4-inch slab, and this mathematical analysis, which is fundamentally sound, is invaluable in road design irrespective of other indeterminate factors.

Various analytical methods have been advanced for determining the minimum thickness of a concrete road. Various assumptions of superimposed loading, bearing power of soil, impact, vehicular speeds, etc., are used and certain definite conclusions are reached.

Mr. H. J. Fixmer, Paving Engineer, Board of Local Improvements, Chicago, Ill., in an article published in "Engineering and Contracting," April 2, 1919, refers specifically to "the distribution of the resultant pressure over an area of subgrade capable of supporting such loads," which naturally requires first-hand knowledge of the allowable pressure the subgrade can safely support. Diagrammatically Mr. Fixmer shows an approximate method of determining the thickness of various types of pavements in connection with wheel concentrations and allowable soil pressure. It is interesting to note that this approximate method gives for an ordinary soil capable

of sustaining 2 tons per square foot, a slab thickness of 4 inches for 1:2:3 concrete, the maximum wheel concentration being taken at 6 tons, or 12,000 lbs., and for a soil capable of supporting 1,200 lbs. per square foot, the slab thickness is 8 inches for a 1:2:4 concrete with the same wheel concentration. Although merely a theoretical demonstration which the author states must be regarded as "educational rather than as an exact solution," the results obtained from the diagram are an aid to paving design. It is rational and sound in that it classes thickness of pavement as a function of subgrade and superimposed loading.

Mr. A. T. Goldbeck, Engineer of Tests, U. S. Bureau of Public Roads, has supervised some interesting experiments in order to determine pressure distribution due to concentrated wheel loads. (Public Roads, Vol. 1, No. 12, April, 1919.) Certain formulae are derived by the author which are interesting. For example:

$S = \frac{3P}{d^2}$ is used to determine the theoretical thickness of a concrete slab at the edges in order to keep the corners from breaking down under truck loads, a condition very common on our thin California roads. Mr. Goldbeck arrives at a theoretical depth of 6½ inches at the sides for a soft subgrade. However, S used is equal to the modulus of rupture=600 lbs. per square inch, and the maximum load P is given as 8,500 lbs.

Actual weights of trucks and truck loads on California roads give heavier concentrations. A single wheel load of 5 tons, or 10,000 lbs., should be provided for. Using the Goldbeck formula, a load P of 10,000 lbs. and a fiber stress S in concrete of 300 lbs. per square inch:

$$S = \frac{3P}{d^2} \qquad d = \sqrt{\frac{3P}{S}} = \sqrt{\frac{3 \times 10000}{300}} = 10 \text{ inches}$$

Hence to avoid triangular breaks, by mathematical analysis we determine a slab thickness of 10 inches is required at the sides.

Again, determining the required thickness of concrete slab, considering two trucks passing and slab supported at center:

Mr. Goldbeck's formula is:

$$S = 8.6 \frac{P}{d^2} \frac{(s-6)}{(s)} + 9.4 \frac{s^2}{d}$$

$$\text{Assuming fc} = 300 \text{ lb.} = S \qquad s = \text{width of road} = 18 \text{ ft.}$$

$$300 = \frac{57332}{d^2} + \frac{3045.6}{d}$$

Whence d=19.77 inches.

In order to be safe from cracking when loaded as above, mathematically we determine that the slab should be 19.77 inches thick.

Present economical practice dictates the construction of concrete roads averaging 7 inches to 8 inches in total thickness, with regulation of traffic by law. In view of this condition, the fallacy of a 20-inch concrete road section is obvious and our mathematical analysis falls down in the face of practice and precedent.

A third analysis of slab thickness (with steel reinforcement), using single concentrations of ten tons, is found in the 1920 Highways Green Book, American Automobile Association. Mr. Wm. S. Thompson, Chief Engineer, Corrugated Bar Co., analyzes a reinforced concrete road slab, treating same both as a simple and as a continuous beam and using a distribution of loading seven times the thickness of slab, and, by the use of the usual formula for reinforced concrete design, arrives at a theoretical effective depth of slab of 5.4 inches + 2½ inches for protection of steel, or a total depth of 8 inches. A 10-inch slab, however, is recommended. Steel in the slab =3.64 lbs. per square foot of pavement surface, or 384,000 lbs. of steel per mile for a 20-foot road.

The steel reinforcement alone on the above design basis would cost approximately $20,000.00 per mile today, and, aside from the soundness or unsoundness of the analysis, **the cost of a road 10 inches thick so heavily reinforced would be prohibitive.** A structure designed to support all possible loads is uneconomical and wasteful, since its design is not based on actualities but mere prophecy; hence theory must be rejected in this case in favor of economical, but nevertheless sound construction policies.

The question then becomes: Shall a road be designed and built on mathematical and theoretical assumptions or by actual analytical cost versus average life of the type, width and thickness of road, **coupled with theory and precedent as guides?** We believe the latter course is the only one that can be logically defended. It is an all too common practice in many municipalities and counties today to design a road to meet **financial limitations** rather than traffic needs and longevity. The very fact that roads of this character have been built furnishes the basis for economical analysis with respect to life and service. We will, therefore, now proceed to analyze the financial soundness of the California 4-inch concrete road on the basis of its first cost, upkeep, interest and reconstruction charges, and we will compare this pavement with thicker slabs in use elsewhere in an effort to determine a more economical type, bearing in mind mathematical determinations, also successful road sections now in use in other states.

Thickness of Concrete Road Slabs by Ultimate Cost Analysis 5.09

Axiomatically, the ultimate success of a system of highways is gauged by the service provided for the cost entailed. Under this test, and unlike most engineering structures, no system of roads becomes a complete failure. Certain sections of pavement in the system may be of inadequate strength to carry the traffic and early show distress and perhaps break up and become total failures. But the pavement itself does not constitute the entire investment in any section of highway. Grading, drainage and incidental structures may, and quite frequently do, constitute the more costly portion of a section of highway, and we must differentiate quite sharply when we analyze a pavement failure, so that the understanding is clear that we are considering only an item of the total expenditure.

In considering in this chapter the cost of the California State highways, we mean only the pavements themselves, and our principal consideration will be given to those pavements completed prior to January, 1916, and constructed of concrete.

The relative cost of all concrete paved sections of State highway completed prior to January, 1916, and used in this comparison, is segregated as follows:

Pavement and surfacing	$3,972,534.00
Grading, drainage and incidental structures	1,625,554.00
Total	$5,598,088.00

Representing approximately 468 miles of completed work.

Paved sections completed subsequent to January, 1916, will not be analyzed from the cost standpoint, as the average service represented to date is less than three years and maintenance records are therefore relatively of much less value. These pavements offer little or no change in design and therefore have no different significance as compared to the pavements to be analyzed.

We have stated that the final and all including test of a highway is the cost for the service provided, and this applies most particularly to pavements. Experience has demonstrated the correctness of the following, that:

1. A pavement properly and adequately designed to meet the conditions of traffic, subgrade and drainage, may have a relatively high initial cost but will most certainly have a long life and low maintenance costs.
2. A pavement designed with little regard to the same requirements may be constructed at a low initial cost but will most certainly be kept serviceable at an excessive cost for maintenance and that for a short term of years only.

That many sections of the California State Highway system answer the latter definition becomes conclusively apparent from a study of their cost.

Primarily a field investigation of the condition of a paved highway system is but partial information as to the worth of such system as an engineering structure. Recently applied bituminous surfacings to concrete pavements may give a section the appearance of a perfect pavement, while the base below may have been the subject of heavy maintenance charges, so heavy in fact as to warrant entire replacement by more proper design. Any conclusion founded only on the appearance of such a pavement might be entirely erroneous, and certainly any statement as to the ultimate value of such a pavement would be the merest guess. Also, predictions from the field standpoint as to the economic worth of sections paved with oiled and bituminous macadam may lead to serious error. The apparent rehabilitation of such sections by heavy patching or surface treatment of the entire section might tend toward a conclusion that maintenance costs were far in excess of their actuality. On the other hand, on heavily patched sections, where new work blended so well with old as to be indistinguishable, and the surface appearance of which was smooth and to proper section, the opposite conclusion might be formed without true knowledge of the facts. Again, the treatment of shoulders with gravel and rock and bituminous surfacing in order to accommodate the ever increasing traffic, can hardly be classified from the viewpoint of ultimate value, by a field inspection as to present condition.

Field investigation is therefore but a supplement, although a valuable one, as will be shown, to the final determination of the success or failure of a pavement. The ultimate analysis must be predicted on **final cost for service rendered.**

A first hand and intimate knowledge of a large proportion of the California highway pavement work over the entire period of construction activity, supplemented by a comprehensive field survey such as has been made, gives the possessor a clear cut idea of the service performed, periods of maintenance activity and probable life of a great area of paved highway. The value of all this lies in its correlation to the examination and analysis of cost and maintenance data. Its application occurs in determining the true explanation of many of the apparent inconsistencies which occur in State highway records of maintenance costs and in the ability to group together, with a fair assurance of accuracy, all these elements that enter into the final cost.

The principal elements of pavement cost may be grouped as follows:

1. Pavement base cost and maintenance.
2. Pavement surfacing cost and maintenance.
3. Shoulder improvement and maintenance.

Their relation, one to the other, in arriving at pavement costs will undergo progressive investigation as the final figures are developed hereinafter.

While the majority of the people individually have sound financial ideas in the conduct of their own business, as Dun and Bradstreet yearly reports amply demonstrate, collectively in the conduct of their municipal, county, State and national business, the financial soundness of much public improvement is given but little consideration. The security behind bond issues to cover work is of such character and amplitude that financial houses look principally into ability to pay and only half heartedly into soundness of contemplated betterment on public work.

Let the same improvement work be undertaken by private interests and the same banking concerns manifest an entirely different attitude toward the details of the proposed work—usually by the employment of experts in the proposed work to examine and report upon the financial soundness of the project itself. The reason is obvious. Financial soundness is the "acid" test of works of any significance and, whether the work be private or public, the final analysis of the soundness of the betterment resolves itself into:

1. A proper design at the minimum ultimate cost to
2. Provide a specific service at
3. A saving or earning power commensurate with said cost.

The application of this test to a transportation line, either railroad or highway, is to determine its value as an economic factor in the development of communication.

Our principal concern here is with proper design at minimum ultimate cost as applied to State highway pavements into which naturally enter as a factor the supplying of a specific service and earning power (or saving). The economics of the transportation itself, involving a lengthy study and analysis of vehicular costs, operation and upkeep, annual tonnage and traction factors, which may be classed as "specific service" together with "earning power" are questions outside of the scope of this report and it will therefore suffice simply to mention their relation to the entire problem.

Our first concern is an analysis of what is meant by ultimate (or final) cost, as applied to California State highway pavements. As an hypothesis we may define this as follows:

The ultimate cost of a pavement is:

(a) The initial total cost of construction

(b) plus interest charges for a period equal to the average life of bonds issued to cover such construction

(c) plus maintenance for the period of **economic** life of the pavement and

(d) plus reconstruction costs—plus interest and maintenance charges for pavement reconstructed within the average bond life to the end of such period.

We have first to consider two alternatives:

1. The construction of a light type of pavement of low first cost and ease of replacement and its renewal once or twice within the bond life, as against
2. A heavy type of pavement of high first cost but of a design sufficiently resistant to provide service for the average bond life.

It will be stated that the construction of a pavement such as is called for in No. 2 is not possible under the rapidly increasing heavy traffic. That a pavement capable of withstanding the traffic of the next five or ten years may be totally inadequate fifteen or twenty years hence; that no one can predict the amount and type of traffic ten, fifteen or twenty years in advance.

That no one can predict, with exactness, the amount and type of traffic twenty years hence is no doubt true—but a proper and comprehensive traffic study over the past ten years would have furnished data today from which a fairly close approximation could be made. And that many State Highway Departments are now conducting such studies and have been for years, is sufficient proof that its value has been demonstrated. Existing traffic studies, while not comprehensive, are available for approximations and these, coupled with an analysis of motor vehicle registration will form an excellent basis for rough traffic predictions, particularly if checked by yearly traffic census in the future.

It may not be possible to design a pavement that will be adequate for traffic twenty or twenty-five years hence without entailing excessive first costs, but we will examine some heavy types of concrete pavements constructed six and seven years ago in comparison with the light type constructed in California at the same time and this may determine a design that would have approximated in its **economical life** the average bond life in our first Highway Act.

It is necessary to define the **economical life** of a pavement and we find very little definite data as a basis of analysis. If we consider the financial soundness of the pavement as an investment, without regard to its earning power, we may determine that the pavement becomes a poor investment when our annual maintenance charges against the same exceed the interest and amortization on the capital necessary to reconstruct—and thus establish the date of replacement. This seems a sound premise in that it takes into consideration the vital element of reconstruction costs. In other words, during a period of high construction costs the pavement will be maintained for service for a longer period than would be the case if labor and materials were comparatively cheap—and again with cheap labor and materials making for low reconstruction costs, an opportune time for reconstruction is apparent.

We will assume, then, for our first analysis, that the economical life of a pavement is that number of years following its construction, to a period when the annual maintenance on the same becomes equal to or greater than the annual interest and amortization charges on the capital necessary to reconstruct the pavement. With the original statement of ultimate cost and this definition of economical life as a basis, we will examine those paved sections of California State Highway constructed prior to January, 1916, dealing with the concrete base pavements only.

Table VII following, is a summary of costs to June 30, 1920, of those cement concrete pavements completed prior to January, 1915, and Table VIII following, is a summary of costs to June 30, 1920, of those cement concrete pavements completed during the year 1915.

Table IX shows pavement base and surfacing maintenance charges for all cement concrete pavements completed in the years 1914 and 1915, together with costs of surfacing distributed in equal yearly increments to date. From Table IX, the maintenance curve, Figure 1, for California Highway pavements has been developed.

Tables X and XI show the pavements of 1914 and 1915 when they have reached the end of their economical life, the cost of reconstructing same and their ultimate cost at the end of the average bond life. Costs of reconstructing are based on present day labor and material prices.

From Table XI it will be seen that the average economical life of these pavements is approximately eleven years and that the grand total cost of these pavements after reconstruction, to bring them to a final life of 25 years, is approximately $34,201,532.00 for the 504 miles. The average cost per mile will be $67,860.00.

NOTE: This cost is low due to the fact that heavy increases in maintenance during the fiscal year 1920-21 are not available, which costs would provide a considerable acceleration to the assumed maintenance curve, Figure 1.

It is also of interest to note that reconstruction work is in progress on seven of the sections noted in the tables and the cost of this work subsequent to June 30, is not available.

It may be argued that costs of surfacing are not proper maintenance charges. As practically all surfacing of California pavements occurs in an effort to prevent disintegration of distressed sections, it is in reality a maintenance operation. As the method used of distributing costs of surfacing makes for lower ultimate costs of these pavements, it cannot be questioned from that standpoint.

It will be noted that shoulder construction and maintenance is not charged in tabulations, although it is also directly related to the maintenance of pavements and would provide a considerable increase in final costs. This matter is analyzed in detail, however, in connection with widths of pavement.

To the extent of the items above noted, the final costs of 4-inch pavements are therefore favored.

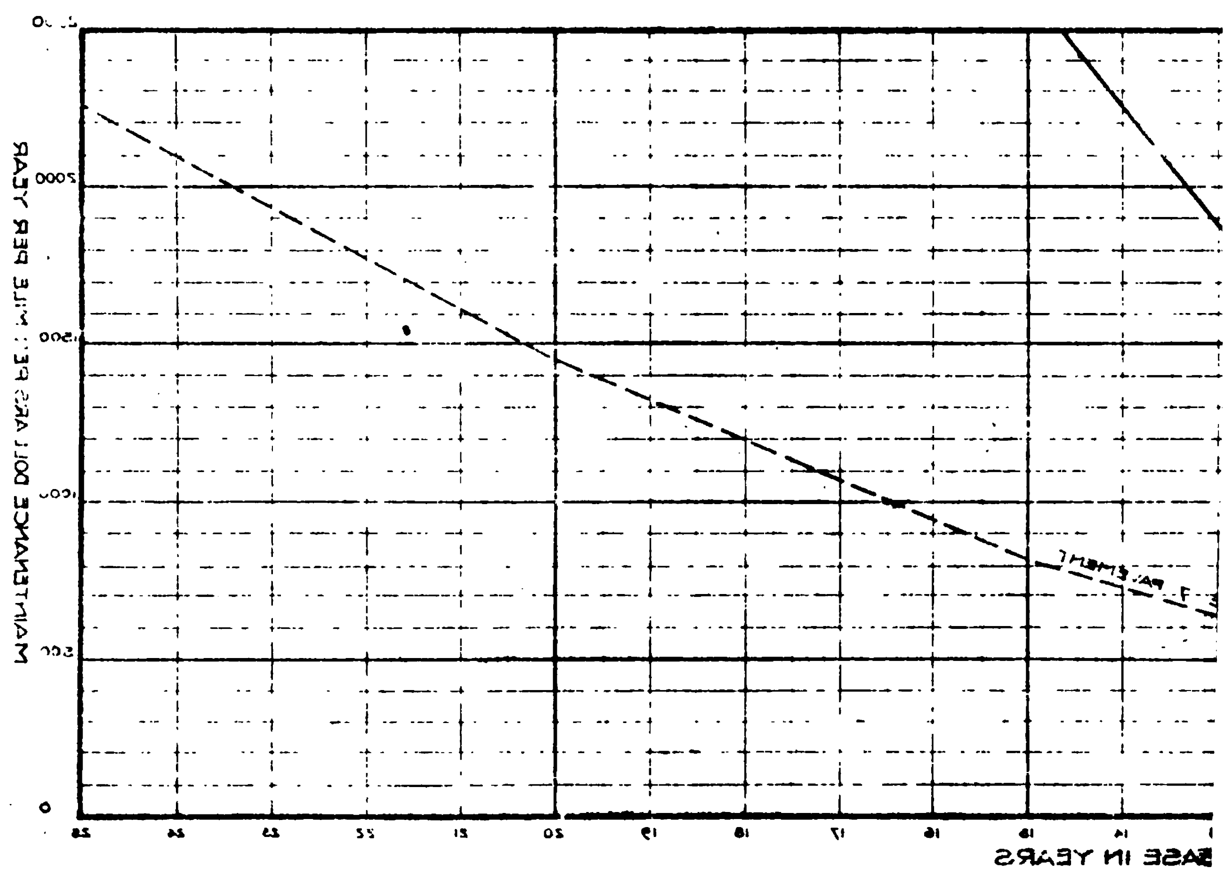
In considering a thicker pavement for comparison with this four-inch base, it becomes apparent that any pavement having only a few years additional economical life would vary but little in final cost. Another limiting factor occurs in the availability of maintenance records on various thicknesses of concrete roads from which to develop maintenance curves.

After considerable experimentation and analysis it was found that a pavement seven inches in thickness provided a favorable basis for comparison and from data obtained from the following states, Washington, Pennsylvania, Maryland, Connecticut, Illinois, it was possible to project a maintenance curve and arrive at the economical life of such a pavement.

The curve developed is shown on Figure 1.

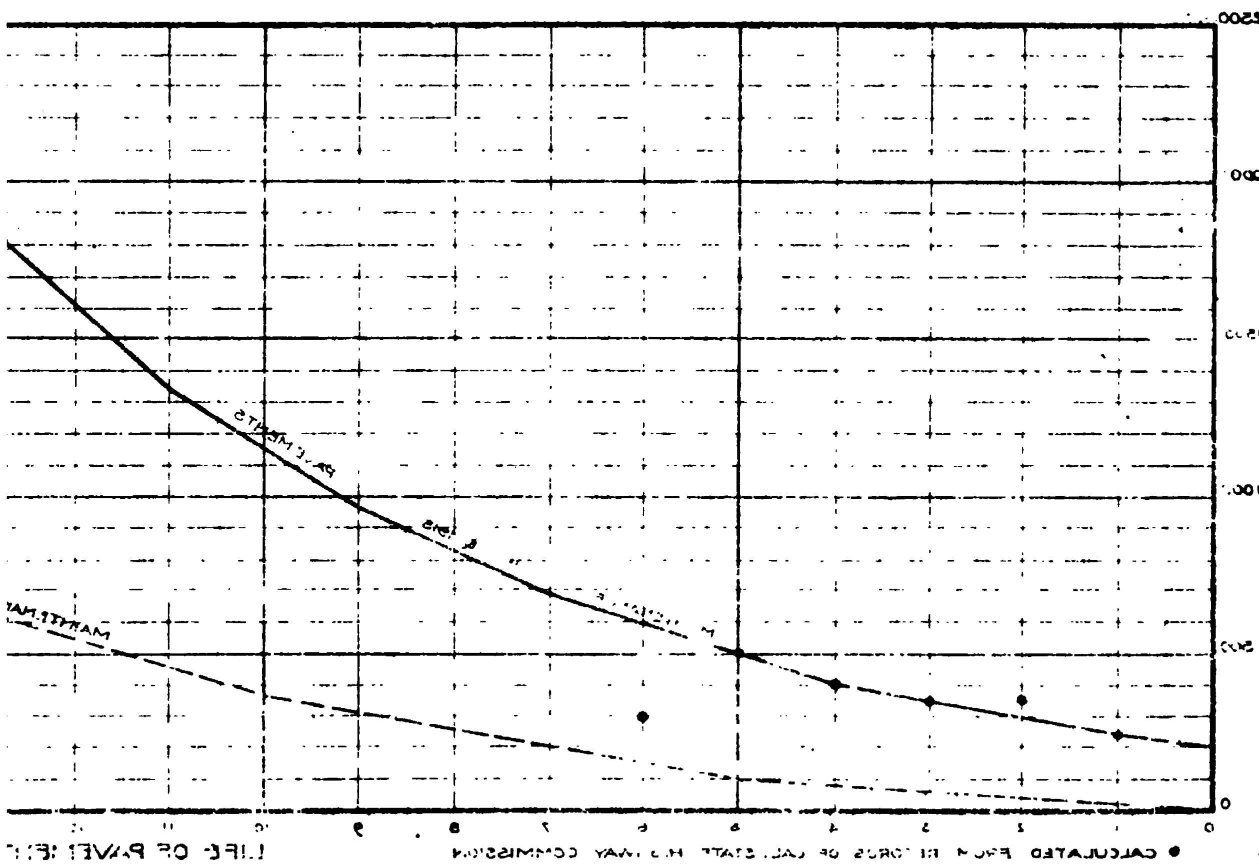
Before proceeding with the development of final cost of this pavement it was decided to add to the first cost, **a charge for adulterating subsoil and for reinforcing pavement over adobe and clay subgrades.** Our maintenance curve shows an economical life of approximately 25 years, but to establish this life more certainly, the foregoing expedients should

ANCE CURVES.



MAINTENANCE DOLLARS PER MILE PER YEAR
0
500
1000
1500
2000
25
24
23
22
21
20
19
18
17
16
15
14
BASE IN YEARS

FIG. 1 MAINTE



2500
2000
1500
1000
500
0
PAVEMENTS
MAINTENANCE
LIFE OF PAVEMENT
● CALCULATED FROM RECORDS OF CAL. STATE HIGHWAY COMMISSION

cover any doubts that may exist. In addition, maintenance data obtained embraced pavements of richer concrete mixture than California specifications and the additional cost due to a 1:2:3½ mixture is considered here. Adulteration of adobe subsoil is assumed as an application of six inches (loose) of gravel and a partial incorporation of the same into the top layer of the subsoil before rolling and compacting. Steel reinforcement is based on square steel bars, ⅜-inch, spaced 12 inches on centers transversely and two ½-inch longitudinal rods each placed six inches from outer edges of pavement.

One-half of all pavement is considered treated as above.

Table XII following, is the development of cost of an average mile of pavement seven inches thick, with the special treatment noted, to a life of 25 years, and we have a final cost of $53,050.00 per mile.

Against this is the final cost of the four-inch pavement, of $67,800.00 per mile.

It appears from this examination of California highway pavements that on main trunk lines subjected to heavy traffic, particularly where subsoil conditions are questionable, thin concrete slabs are entirely unsound for pavement design.

It is recognized that the increase in fast-moving heavily loaded traffic has been enormous since these pavements were built, and it is estimated that this traffic will continue to increase in successive years, **but that loading will be limited.**

Past experience should provide a tangible basis for future guidance, and if this experience in California is analyzed as we have attempted to do, it becomes apparent that the adoption of a five-inch slab at the present day may prove only a repetition of the experience with the four-inch slab of the past, and we have gained nothing.

That practically every community in California has been educated to the value of hard paved roads is shown in the voting of county bond issues for highways to supplement the great State system. The people are willing to pay for good roads, and road officials and engineers in charge of these important problems must recognize that road design calls for comprehensive and intensive study, foresight and courage, if the road funds of the county, State or country are to be economically expended.

The important principle that we advance here is an old one; first cost is not always a wise guide in the design of engineering structures, and miles of highway can well be set aside in our future work for quality in construction.

Of vital concern in this same connection is the record of pavement thickness adopted by other States and Table XIII following is a record obtained by correspondence with thirty-five Highway Departments to this end. It will be noted that many states are calling for pavements eight and nine inches thick and that of all of the states listed, none use as light a pavement as the recently-adopted 5-inch minimum of the California Highway Commission.

From every standpoint of comparison that the subject may be approached, the fallacy of the four-inch pavements is shown. It is our belief that the five-inch pavement will be the subject of a like comparison and is in no way suited to modern traffic conditions on our main heavily traveled highways.

Memorandum

Total mileage of highways represented in Tables X and XI following = 483.9.

As numerous sections in this total are 18 feet wide and a few 20 and 24, this mileage has been expanded to the equivalent mileage of 15-foot pavement = 504., and this latter figure used in determining the cost per mile = $67,860.00.

Table VII

COST OF PAVEMENTS COMPLETED IN 1914

WITH

MAINTENANCE AND INTEREST TO JUNE 30, 1920

Contract No.	County	Route and Section	Length	Approx. No. Yards	Cost per Yard	Total Cost Concrete Pavement	Engineering during Construction	Interest at 5% to June 30, 1920	Total Maint. Pavement Base to June 30, 1920	Reconstruction Expenditure	Total Cost of Pavement to June 30, 1920
5	Stanislaus	4-A	12.04	11,775	$6.73	$ 79,255.04	$ 3,646.65	$ 24,870.51	$ 5,738.63	....	$ 113,511
6	Merced	4-D	9.74	9,545	5.71	54,502.48	3,013.56	17,254.81	3,893.97	....	78,664
7	San Diego	2-A	8.42	8,227	6.02	49,513.80	2,632.55	15,643.90	1,992.44	....	69,783
8	Fresno	4-C	9.56	9,334	5.40	50,395.47	2,232.18	15,788.30	854.72	....	69,270
9	Madera	4-A	9.95	9,773	5.52	53,928.50	2,963.85	17,067.70	2,742.44	....	76,702
10	Madera	4-C	6.83	6,687	5.52	36,935.24	3,171.00	12,031.87	796.45	....	52,935
11	Merced	4-C	10.86	10,684	6.13	65,513.47	4,363.25	20,963.02	4,798.69	$1,348.61	96,987
12	Sacramento	3-A	1.85	1,827	5.97	10,900.78	1,611.00	3,753.53	242.99	....	16,508
13	Placer	3-A	9.92	9,713	6.32	61,391.05	4,910.92	19,890.59	2,862.83	....	89,055
17	Los Angeles	2-A	6.55	6,410	5.95	38,138.86	2,445.81	12,175.40	1,462.99	....	54,223
21	Los Angeles	2-B	10.13	10,041	6.39	64,131.02	4,635.88	20,630.07	2,760.35	1,448.57	93,606
©23–28	Santa Clara	2-B	17.30	17,503	6.03	105,595.13	3,952.82	32,864.37	10,499.30	....	152,912
25	Stanislaus	4-B	9.58	9,407	5.69	53,476.69	5,285.64	17,628.70	1,305.65	....	77,697
30	San Diego	2-B	10.45	10,441	6.51	67,932.09	3,093.00	21,307.53	1,615.91	....	93,949
31	Ventura	2-A	7.34	7,202	7.02	50,555.21	2,640.91	15,958.84	471.65	....	69,627
37	San Bernardino	19-A-B	6.61	7,747	5.49	42,555.23	2,918.69	13,642.18	981.14	....	60,097
38	San Bernardino	9-C-B	5.83	6,832	5.42	37,015.60	3,239.22	12,076.45	803.69	....	53,135
39	San Diego	2-C	8.03	7,919	6.64	52,597.97	2,170.96	16,430.70	757.38	4,466.79	76,424
40	Orange	2-D-E-F	11.16	13,120	5.55	72,842.75	4,183.54	23,107.89	196.50	....	100,331
43	Riverside	19-A	9.34	10,926	5.22	57,036.23	3,664.18	18,210.11	484.26	....	79,395
47	Fresno	4-B	7.99	10,423	6.39	66,560.51	2,523.11	20,725.08	680.43	....	90,489
50	Kern	4-D	10.14	10,304	5.54	57,112.43	3,202.32	18,094.42	1,995.63	....	80,405
53	San Bernardino	9-D	1.69	1,956	5.26	10,293.75	969.77	3,379.06	409.34	....	15,052
1–26 29–54	San Mateo	2-A	10.32	20,145	4.91	98,936.52	5,744.34	31,404.26	692.39	....	136,777
	Totals	....	211.63	227,941	......	$1,337,115.82	$79,215.15	$424,899.29	$49,039.77	$7,263.97	$1,897,534

©Records California Highway Commission indefinite; quantities either computed or assumed.

Table VIII

COST OF PAVEMENTS COMPLETED IN 1915

WITH

INTEREST AND MAINTENANCE TO JUNE 30, 1920

Contract No.	County	Route and Section	Length	Approx. No. Yards	Cost per Yard	Total Cost Concrete Pavement	Engineering during Construction	Interest at 5% to June 30, 1920	Total Maint. Pavement Base to June 30, 1920	Reconstruction Expenditure	Total Cost of Pavement to June 30, 1920
33	Los Angeles	2-C	11.28	11,027	$7.11	$ 78,455.70	$ 4,648.75	$20,776.11	$ 1,228.66	$ 6,474.75	$111,583.97
46	San Bernardino	9-A	10.36	12,282	5.53	67,818.04	4,303.38	18,030.35	323,24		90,475.01
48	Fresno	4-A	8.21	8,020	5.95	47,704.74	2,867.88	12,643.15	2,695.98		65,911.75
51	Kern	4-E	8.94	8,784	5.49	48,242.68	2,881.64	12,781.08	1,230.31		65,135.71
52	Ventura	2-D-E	8.02	7,448	7.02	52,255.46	1,664.24	13,479.92	253.44		67,653.06
⊙55	San Luis Obispo	2-C	8.35	8,158	8.12	66,209.46	2,186.88	17,099.08	1,759.81		87,255.29
58	San Diego	2-D	11.59	10,839	6.41	69,482.51	4,819.64	18,575.54	298.07		93,175.76
61	Alameda	5-C	3.12	4,155	5.72	23,749.78	1,437.48	6,296.82	1,899.60		33,383.68
63	Kern	4-F	12.45	12,157	6.92	84,148.01	2,961.90	21,777.48	3,657.19	14,835.18	127,379.76
67	Kern	4-C	12.98	12,691	8.43	106,952.71	5,038.29	27,997.75	4,520.89		144,509.64
69	Merced	4-A	14.19	13,935	6.52	90,828.63	4,930.59	23,939.81	3,783.16	1,919.40	125,401.59
⊙35-72	Santa Clara	2-C-2	13.59	13,328	6.09	81,129.76	4,342.64	21,368.10	7,504.96		114,345.46
⊙73	Ventura	2-F-G	5.05	2,590	6.70	17,347.59	795.22	4,535.70	210.84		22,889.35
74	Solano	7-C	8.80	8,552	7.37	63,000.28	3,271.70	16,567.99	2,736.95		85,576.92
76	Tehama	7-A	8.79	8,268	6.57	54,285.71	3,582.35	14,467.01	190.32		72,525.39
77	Glenn	7-C	6.94	7,129	5.60	39,913.61	1,791.20	10,426.20	569.31		52,700.32
78	Los Angeles	4-D	12.62	10,181	8.37	85,236.35	6,469.34	22,926.42	1,098.80		115,730.91
80	Colusa	7-A	10.82	11,551	6.43	74,265.34	4,763.39	19,757.18	694.37		99,480.28
81	Ventura	2-B	11.14	9,646	6.78	65,412.02	3,296.25	17,177.07	1,440.85	735.04	88,061.23
82	Yolo	7-A	11.75	12,492	6.37	79,512.54	3,900.45	20,853.25	599.78		104,866.02
84	San Luis Obispo	2-E	13.42	12,857	8.46	108,959.83	4,736.97	28,424.20	4,397.32		146,518.32
89	Santa Clara	5-A	6.79	8,897	5.90	52,452.42	3,398.78	13,962.80	650.74		70,464.74
⊙90-108	Alameda	5-A	10.86	12,073	5.72	69,024.48	3,948.82	18,243.32	3,193.13		94,409.75
94	San Diego	12-B	1.56	1,522	8.42	12,813.51	685.42	3,374.73	63.26		16,936.92
97	Orange	2-B	9.36	9,170	6.07	55,649.52	2,820.31	14,617.46	138.12		73,225.41
98	Orange	2-C	7.40	7,580	6.03	45,741.35	2,847.68	12,147.26	1,354.68		62,090.97
114	Solano	7-B	8.06	7,945	6.67	52,979.92	2,765.61	13,936.38	1,521.31		71,203.22
119	Orange	2-A-2	5.53	5,450	6.27	34,149.36	1,645.73	8,948.77	1,859.25		46,603.11
125	Tulare	4-E	5.34	5,106	6.14	31,358.53	1,462.58	8,205.28	1,511.46		42,537.85
131	Monterey	2-A	4.94	4,817	7.72	37,180.08	1,402.46	9,645.64	2,547.40		50,775.58
	Totals		272.25	268,650		$1,796,259.92	$95,667.57	$472,981.85	$53,933.26	$23,964.37	$2,442,806.97

⊙Records California Highway Commission indefinite; quantities either computed or assumed.

TABLE IX

TOTAL PAVEMENT MAINTENANCE BY YEARS

Including surfacing Costs and Maintenance
but excluding Shoulder Costs & Maintenance.

		1914	1915	1916	1917	1918	1919	1920	TOTALS
PAVEMENT BASE	1914		2391.13	3398.26	5258.53	12198.01	17252.42	9673.07	50171.42
	1915			5421.29	6364.15	13197.26	19142.06	12778.78	56903.54
PAVEMENT SURFACE	1914	5875.99	16066.31	40379.84	32486.37	44715.79	65147.59	9096.12	213768.01
	1915	12.00	5446.64	22107.88	22955.49	25978.50	39133.15	12593.97	128227.65
TOTALS.		5887.99	23904.08	71307.29	67064.54	96089.56	140675.22	44141.94	449070.60
SURFACING COST			91875.00	91875.00	91875.00	91875.00	91875.00	91875.00	

Table X

ULTIMATE, 25-YEAR COSTS OF PAVEMENTS COMPLETED IN 1914

County	Route and Section	Initial Cost of Pavement Including Engineering	Interest to End of Bond Period 25 Years	Life	Total Mtce. to End of Economical Life	Reconstruction, Interest and Maintenance to End of Bond Period			Final Cost of Pavement
						Reconstruction	Interest	Maintenance	
Stanislaus	4-A	$ 82,902	$ 103,627	11	$ 85,749	$ 242,404	$ 169,683	$ 154,678	$ 839,043
Merced	4-D	57,516	71,895	13	103,215	186,562	111,337	62,000	592,525
San Diego	2-A	52,146	65,183	11	59,967	169,382	118,567	73,439	538,684
Fresno	4-C	52,628	65,785	11	68,086	192,189	134,532	122,817	636,037
Madera	4-A	56,892	71,115	11	70,864	201,094	140,766	127,822	668,553
Madera	4-C	40,106	50,133	11	48,643	137,644	96,351	87,745	460,622
Merced	4-C	69,877	87,346	11	77,345	219,801	153,861	139,518	747,748
Sacramento	3-A	12,512	15,640	11	13,176	37,570	26,299	23,767	128,964
Placer	3-A	66,302	82,878	11	70,650	199,930	139,951	127,442	687,153
Los Angeles	2-A	40,585	50,731	11	46,649	131,949	92,364	84,148	446,426
Los Angeles	2-B	68,767	85,959	11	72,146	206,403	144,482	130,140	707,897
Santa Clara	2-B	109,548	136,935	11	123,211	358,992	251,294	222,253	1,202,233
Stanislaus	4-B	58,762	73,452	11	68,229	193,569	135,498	123,074	652,584
San Diego	2-B	71,025	88,781	11	74,425	214,438	150,107	134,251	733,027
Ventura	2-A	53,196	66,495	11	52,275	148,209	103,746	94,297	518,218
San Bernardino	19-A-B	45,474	56,842	13	70,046	156,558	93,935	57,652	480,507
San Bernardino	9-C-B	40,255	50,319	12	50,849	138,069	89,745	61,780	431,017
San Diego	2-C	54,769	68,461	11	57,190	162,874	114,012	103,161	560,467
Orange	2-D-E-F	77,026	96,283	12	97,337	265,064	172,292	118,262	826,264
Riverside	19-A	60,700	75,875	12	81,463	220,842	143,547	98,976	681,403
Fresno	4-B	69,084	86,355	13	84,670	208,624	125,174	69,689	643,596
Kern	4-D	60,315	75,394	11	72,217	211,239	147,867	130,269	697,301
San Bernardino	9-D	11,264	14,080	12	14,740	39,576	25,724	17,909	123,293
San Mateo	2-A	104,681	130,851	15	159,671	391,792	195,896	59,670	1,042,561
Totals	....	$1,416,332	$1,770,415	.....	$1,722,813	$4,634,774	$3,077,030	$2,424,759	$15,046,123

Table XI

ULTIMATE, 25-YEAR COSTS OF PAVEMENTS COMPLETED IN 1915

County	Route and Section	Initial cost of Pavement Including Engineering	Interest to End of Bond Period 25 Years	Life	Total Mtce. to End of Economical Life	Reconstruction, Interest and Maintenance to End of Bond Period			Final Cost of Pavement
						Reconstruction	Interest	Maintenance	
Los Angeles	2-C	$ 83,104	$ 103,880	11	$ 80,336	$ 227,016	$ 158,911	$ 144,914	$ 798,161
San Bernardino	9-A	72,121	90,151	12	90,360	247,940	161,161	109,785	771,518
Fresno	4-A	50,573	63,216	11	58,472	165,124	115,587	105,473	558,445
Kern	4-E	51,124	63,905	11	63,671	180,738	126,517	114,852	600,807
Ventura	2-D-E	53,920	67,400	10	46,372	154,230	115,672	124,085	561,679
©San Luis Obispo	2-C	68,396	85,495	11	59,469	167,962	117,573	107,272	606,167
San Diego	2-D	74,302	92,877	10	67,013	224,267	168,200	179,320	805,979
Alameda	5-C	25,187	31,484	13	33,063	83,020	49,812	27,213	249,779
Kern	4-F	87,110	108,887	11	88,669	250,311	175,218	159,945	870,140
Kern	4-C	111,991	139,989	11	92,444	261,269	182,888	166,754	955,335
Merced	4-A	95,759	119,699	11	101,061	286,741	200,719	182,299	986,278
©Santa Clara	2-C-2	85,472	106,840	11	96,788	274,291	192,004	174,591	929,986
Ventura	2-F-G	18,143	22,679	7	15,428	58,674	52,807	134,870	302,601
Solano	7-C	66,272	82,840	11	62,674	176,169	123,318	113,054	624,327
Tehama	7-A	57,868	72,335	11	62,602	170,958	119,671	112,925	596,359
Glenn	7-C	41,705	52,131	11	49,427	145,981	102,187	89,158	480,589
Los Angeles	4-D	91,706	114,632	10	72,969	228,536	171,402	195,257	874,502
Colusa	7-A	79,029	98,786	12	94,372	235,584	153,130	114,660	775,561
Ventura	2-B	68,708	85,885	10	64,411	201,423	151,067	172,360	743,863
Yolo	7-A	83,413	104,266	12	102,483	255,015	165,760	124,515	835,452
San Luis Obispo	2-E	113,697	142,121	11	95,577	265,290	185,703	172,407	974,795
Santa Clara	5-A	55,851	69,814	13	71,954	178,012	106,807	59,222	541,660
Alameda	5-A	72,973	91,216	12	94,721	245,229	159,399	115,083	778,621
San Diego	12-B	13,499	16,874	11	11,110	31,341	21,939	20,041	114,804
Orange	2-B	58,470	73,087	11	66,662	188,745	132,121	120,248	639,333
Orange	2-C	48,589	60,736	11	52,703	155,263	108,684	95,068	521,043
Solano	7-B	55,746	69,682	11	57,403	162,346	113,642	103,547	562,366
Orange	2-A-2	35,795	44,744	11	39,385	112,101	78,471	71,044	381,540
Tulare	4-E	32,821	41,026	11	38,031	105,379	73,765	68,603	359,625
Monterey	2-A	38,583	48,229	11	35,183	99,197	69,438	63,464	354,094
Totals		$1,891,927	$2,364,906		$1,964,813	$5,538,152	$3,853,573	$3,542,038	$19,155,409

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Table XII

ULTIMATE COST OF AN AVERAGE MILE OF 7-INCH PAVEMENT BUILT IN 1914-1915 WITH REINFORCEMENT AND GRAVELED SUBGRADE FOR ONE-HALF MILE

Cubic Yards per Mile	Cost of Concrete at $7.18 per Cubic Yard Incl. Reinforcement	Gravel Subgrade at $2.00 per Cu. Yd. (use ½)	Cost of Pavement	Engineering	Initial Cost of Pavement	Interest for 25 yrs. at 5%	Total Maintenance for Life of 25 years	Total Cost of Pavement
1,710	$12,277.80	$1,466.00	$13,743.80	$824.63	$14,568.00	$18,210.00	$20,272.00	$53,050.00

Table XIII

THICKNESS OF CONCRETE ROAD SLABS IN VARIOUS STATES

	Thickness in Inches at Sides	Thickness in Inches at Center	Remarks
Alabama	5	7¼	With 2" Asphaltic Surfacing
Arizona	6	6	
Arkansas	7	8	
Colorado	6	7½	
Connecticut	6	8	
Delaware	6	8	
Georgia (Spec.)	6	6	
Idaho	5½	6½	
Illinois	8	8	
Indiana	6	8	
Iowa	7	8	
Kansas	6	8	
Maine	7	9	
Maryland	6	8	
Massachusetts	5	7¼	
Michigan	6	8	
Minnesota	7	8	
Missouri	6-7	8-9	
Montana			
Nebraska	6½-7	8-8½	
New Mexico	6	6	
New York	6	8	
North Carolina	7	7	
Ohio	6-8	8-10	
Oregon	7	7	
Pennsylvania	5-6	7-8	Reinforced
Rhode Island	6	8¼	
Tennessee	7	7	
Texas	5-6	7-8	
Vermont	7	9	
Virginia	5-6	7-8	
Washington	6	7½	
West Virginia	6	8	
Wisconsin	7	8	
Wyoming	{4, 6}	{7, 6}	With 1½" Asphaltic Surfacing
Skagit Co., Washington	7	7	

Buckling vs. Expansion Joints 5.10

General practice throughout the State highway system in California has been to allow the concrete road slabs to develop transverse cracks at will. These cracks usually appear a short time after completion of the road, except in the case of rapid drying out, when the shrinkage will develop high tensile stresses, causing cracking before the section is thrown open to traffic.

The transverse cracks are very variable. In some cases, where concrete has been laid late in the season or in the cool coast sections, transverse cracks are noticeably far apart and fairly uniform in appearance. The reverse is true in the hot valleys.

It is claimed that this method of providing expansion joints through natural contraction cracks is economical and satisfactory. **The economical feature does not appear to be borne out by facts**; in addition, a crude, unsightly, irregular joint can hardly be claimed as satisfactory construction.

One of the most serious defects due to natural joints noticed on the State Highway system, is the tendency of the road slab to heave or buckle at a transverse crack. This is due to lack of provision for excessive or high temperature changes. The use of the haphazard natural joint rather than the uniformly spaced asphalt-filled construction joint or scientifically-placed elastic joint, promotes buckling failures and the amount of concrete pavement on the State system that has been taken up and replaced due to this one cause is sufficient to cause grave doubt as to the economy of the method.

The lack of uniform expansion or filled construction joints frequently causes a section of concrete road to be broken into small rectangular segments, thus increasing the possible area of failure and disintegration by presenting to traffic innumerable edges, which usually break back in a triangular form at the shoulders or slowly disintegrate across the entire width of roadway under the impact of traffic. The installation of uniform expansion joints at stated intervals reduces transverse cracks to a minimum, thus controlling to a marked degree triangular breaks, joint disintegration and failure of slab by buckling. A buckled joint, even if it remains intact, is an obstruction on an otherwise smooth paved road. The jar of traffic or impact eventually accomplishes the destruction of the joint and contiguous concrete area. In view of the foregoing it would appear both economical and sound engineering practice for the State to modify the present method of using haphazard contraction cracks for expansion, substituting therefore the modern, elastic joint of known efficiency or the uniformly spaced construction joint, asphalt filled.

It has been claimed that minor buckling will occur, and hence impact or shock is not eliminated, even with regularly spaced elastic expansion joints. This apparently is not general and where ample joint width is provided for abnormal temperature range, should not occur.

It is conceded that careful maintenance of transverse cracks by filling with "D" or "E" grade asphalt will protect these multiple edges from the injurious effects of traffic. But this maintenance must be continuous and efficient to accomplish the result desired and, in any event, is ineffectual to prevent buckling or triangular joint failure.

It has been claimed that the application of a thin bituminous top to a concrete pavement removes some of the objections to irregular natural joints. This is true from the purely esthetic standpoint but structurally unsound for the reason that the fractures and failures due to expansion buckling are not prevented. In the case of the same concrete base covered with 1½ to 2 inches of Topeka, sheet asphalt or other plant mixed wearing surface, the expansion joint is an unnecessary expense proven in the light of experience and may well be omitted.

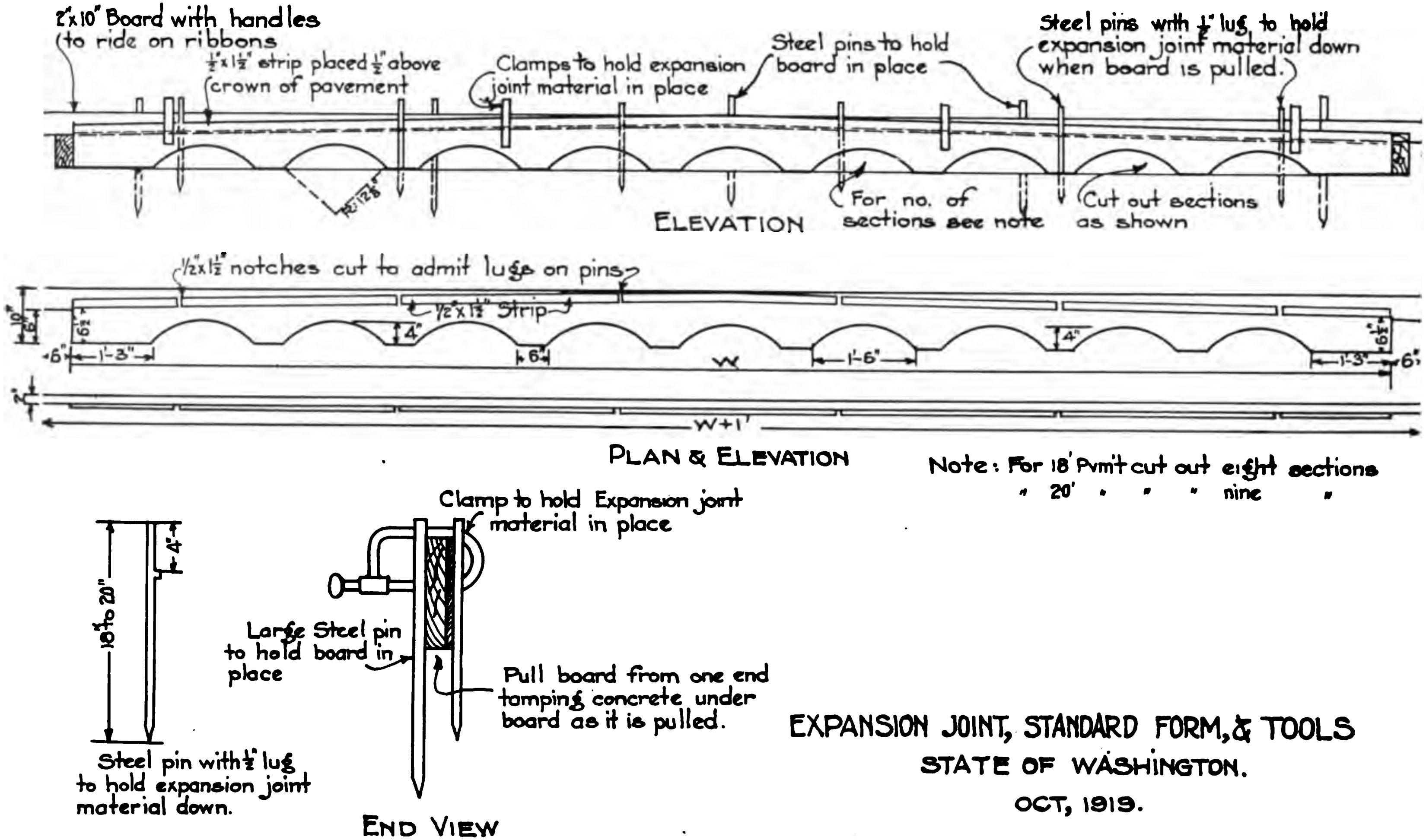
With unsurfaced concrete, the natural or irregular expansion joint is, as already stated, a source of structural weakness, due to multiplicity of edges. In addition, its lack of uniformity, its irregular and ragged appearance and its variation in segmental width to oppose the forces of temperature variation, make it crude and unscientific, thus promoting failures of the type already discussed.

Concrete expands approximately .000006 of its length per degree Fahrenheit rise of temperature. For a 30° variation, this movement amounts to about ¼ inch per 100 feet of length. In practice, however, it is customary to provide three or four times this amount per 100 feet in order to take care of unusual temperature changes. In California, in the valleys of the Sacramento and San Joaquin, in the Imperial desert country and in many other sections of the State, temperature variations are much greater than 30°, and, while the almost universal practice throughout the United States of spacing joints 25 to 33 feet apart would appear to be logical and proper for this State, the thickness of the filler should naturally be variable, dependent on the extremes of temperature in the section to be improved. This thickness will seldom exceed ½-inch in 30-foot panels.

Many types of expansion joints have been used to date, their popularity dependent more upon advertising and the ability of a sales organization, rather than the intrinsic worth of the article.

So-called armored joints, submerged joints, steel plate protection joints and numerous other types, under traffic and temperature changes, have given indifferent results.

In some of the counties in California today, it is the practice to space expansion joints 33 feet on centers and to reinforce the slab on each side of the joint with wire mesh or steel bars. In the light of Oregon and Washington experience and practice, such an elaborately-



EXPANSION JOINT, STANDARD FORM, & TOOLS
STATE OF WASHINGTON.
OCT, 1919.

reinforced joint would appear to be unnecessary. The need for a simple, low-cost method of providing for expansion in concrete slabs is apparent, and in this connection, the Washington State Highway practice is suggested for California, naturally modified to suit climatic conditions. This simple process merely provides a strip of elastic material—usually two layers of asphalt-saturated wool-felt, with a bituminous filler of medium to high penetration. It is firm yet very resilient and, when pressed between the fingers, slowly responds to the pressure exerted. The material, cut into suitable lengths and widths, is placed at intervals of approximately 30 feet. By the use of an arched wooden template, the filler strip is held in position while concrete is worked through the arch openings of the template around the bottom of the filler. The template is then removed and the concrete poured in the usual manner. No reinforcement, steel plates or armored joints are used; simply the strip of bituminous filler at the required interval.

The simplicity and economy of the method is apparent. In Washington, the elimination of triangular breaks or failures at the joints and the almost complete absence of buckling on plain unsurfaced concrete roads is strikingly noticeable, thus after a period of some five years the efficiency of the joint has been fully demonstrated in that state. The additional cost of such insurance against triangular breaks and buckling is low. In this State the average cost of 30-feet ⅜-inch joints should not exceed .19 cents per cubic yard, or approximately .032 cents per square yard of concrete, and the additional expense is more than warranted in the light of experience and general paving practice throughout the country. Statistics for 1920 show that of 48 states engaged in the construction of concrete roads, 35 states or 73 per cent install expansion joints, while 9 states provide some type of construction joint. Since the compilation of these figures, however, there is a gradual movement by many Eastern states to eliminate expansion joints, allowing the concrete to crack where it will. After an experience similar to that in California by the adoption of this method, it is safe to predict a return to either the filled construction joint or the special expansion joint.

Surface Crazing and Suggested Remedies 5.11

Hair checks or crazing on the surface of a freshly laid concrete road is not only a source of worry to both engineer and contractor, but results in a weakened surface and often leads to disintegration. These small irregular cracks, often one-half inch or more in depth, appear in group formation. They are particularly noticeable on the highways of this State in the hot or arid sections. They are not confined exclusively to these localities, however, as is evidenced by sections along the coast in Santa Barbara County and on the new concrete highway over the Ridge Route in Southern California. The cause is somewhat indeterminate but may be due in part to any one of the following reasons:

- (a) Rapid drying out of concrete surface due to high temperatures and dry hot winds.
- (b) Absorption of moisture from concrete due to dry sub-base.
- (c) Lax or improper curing methods.
- (d) Dirty aggregate.
- (e) Porous rock of high absorption qualities.
- (f) Inferior cement.

One of the simplest mechanical methods used to prevent crazing and which should be given a trial here, is a canvas covering or canopy on light wooden battens, crowned to allow an air space between pavement and frame. A contractor would only need to equip himself with frames sufficient for one day's run of concrete, or the State could well afford to furnish same when called upon by the resident engineer. The canvas on the frame is kept wet down during the heat of the day, thus controlling rapid evaporation of moisture from concrete and

consequent irregular surface shrinkage, which is probably the most frequent cause of hair checks or crazing.

An excellent method used in the State of Washington is to thoroughly soak wide strips of canvas and gently lay these "wet blankets" on the freshly setting concrete surface. These can be removed as soon as the concrete has hardened sufficiently and the dike curing method used.

Absorption of moisture by the sub-base is considered as a frequent cause of surface checking. The light sprinkling of subgrades just ahead of the mixer as adopted by the State forces is totally inadequate to prevent absorption of a large amount of moisture from the concrete. Thus, not only is the lower strata of concrete weakened, but the surface scarred with unsightly checks and cracks.

Improper curing, dirty aggregates, porous rock and inferior cement are merely enumerated as possible causes. These are readily and easily controlled. The State inspection methods are efficient enough to eliminate these possibilities, therefore, if crazing occurs from such a source it would be rather the exception than the rule.

While every Division Engineer on the State Highway system has struggled more or less with the crazing problem, no solution has apparently been worked out by Sacramento Headquarters to date. It is serious enough to warrant a very careful study and investigation as to cause and effect, with a view to developing proper and adequate remedial measures.

The Effect of Alkali on Concrete Roads 5.12

At the instigation of the California State Automobile Association, the Department of Civil Engineering, University of California, recently made some investigation of bibliography as to the effect of alkali on concrete structures. Following is a brief summary of the results:

> "The reliability of existing information on the disintegration of concrete by alkali is questionable. This statement does not apply to the publications of the Bureau of Standards, Bulletins 12, 44 and 95, which are without question the most important contributions to the literature on this subject. Other investigations have been made, but taken as a whole, the results of investigations and tests are not conclusive. Future study, based on the present information, will no doubt yield important results.
>
> "The most important examples of certain failures which have been reported are in Canada. Many of the articles telling of these failures describe only the extent of disintegration and attribute the cause to alkali because of its presence in the surrounding soil. In no case do they give the history of the concrete, which may have been made with bank-run gravel (which is rarely of good grading) and sand with high organic content, or may have been prepared with an excess of water or under conditions which would yield concrete of low resistance to stress and weathering. In Canadian territory the disintegration may have been hastened by frost action as well.
>
> "One important structure which shows disintegration is the Winnipeg aqueduct (see Engineering News-Record 84, 1097, June 3, 1920), but there are many instances where concrete is satisfactorily withstanding the forces which disintegrate some concrete.
>
> "The alarm shown by certain writers does not seem to be justified by the facts. The subject is nevertheless very important and is being investigated by a committee of 12 engineers appointed by the Engineering Institute of Canada and the Portland Cement Association under the direction of Duff Abrams, who is planning to conduct experiments in various parts of the United States. An attempt is also being made to interest the Research Council of Canada."

On the west side of the Sacramento Valley, in Glenn County, an 8.6 mile stretch of 1:2½:5 lean concrete road 4″ thick and 4 years old. has disintegrated and gone to pieces in so many places that the greatest portion must be placed in the complete failure class. This road, while now being temporarily repaired, must be completely rebuilt eventually. Three of the principal causes advanced as the reason for this failure are:

(a) The disintegrating effects of alkali on the concrete.
(b) Saturation of subgrade due to rice irrigation.
(c) Heavy motor truck hauling from rice fields.

The latter condition (c) is apparently within the hands of the State to control; the Motor Vehicle Act specifies the allowable wheel concentrations. Saturation of subgrade (b) is a serious matter; the solution is stereotyped, viz.: "Drainage,—remove the cause." Alkali, however, is an altogether different problem and one still in the experimental stage as regards cause, effect and remedy.

With the three factors, (a), (b) and (c) each a contributing cause of failure to the section mentioned, the injurious effects of the alkali, while apparent, are more or less indeterminate. The general appearance of the road would at first glance indicate a low grade of concrete, lean, poorly mixed and cured. Such a concrete, being naturally more or less porous and absorbent, would offer fertile ground for the attacks of alkali in combination with a subgrade saturated with alkaline waters high in the sulphates, particularly magnesium and sodium sulphates (See Eng. & Contr. Vol. XIV, No. 11, 3/15/16) (Eng. News-Record 4/12/17).

In any event, the failure brings to the attention of road engineers in California the possible danger of building a concrete road over alkali soils. Such sections are quite common in California. They are found on the main trunk and lateral highways in Merced, Butte, Glenn and Colusa Counties; on the proposed Cuyama and Cholame laterals in Santa Barbara and San Luis Obispo Counties and in many other parts of the State. The question is important enough to require research, investigation and experimentation. The failure of one ten-mile section of road may mean a loss of several hundred thousand dollars. Under such a possibility what business house would fail to insure itself against disaster?

Some experiments are now under way in the State Laboratory at Sacramento, the scope of the research being somewhat restricted. The subject is important enough to warrant field experiments and test sections in conjunction with more elaborate laboratory research and investigation. Practical experiments in the field such as a bituminous subgrade seal coat, dense rich concrete of high ultimate strength and low absorbent qualities, or some other equally simple method may easily prove to be the solution.

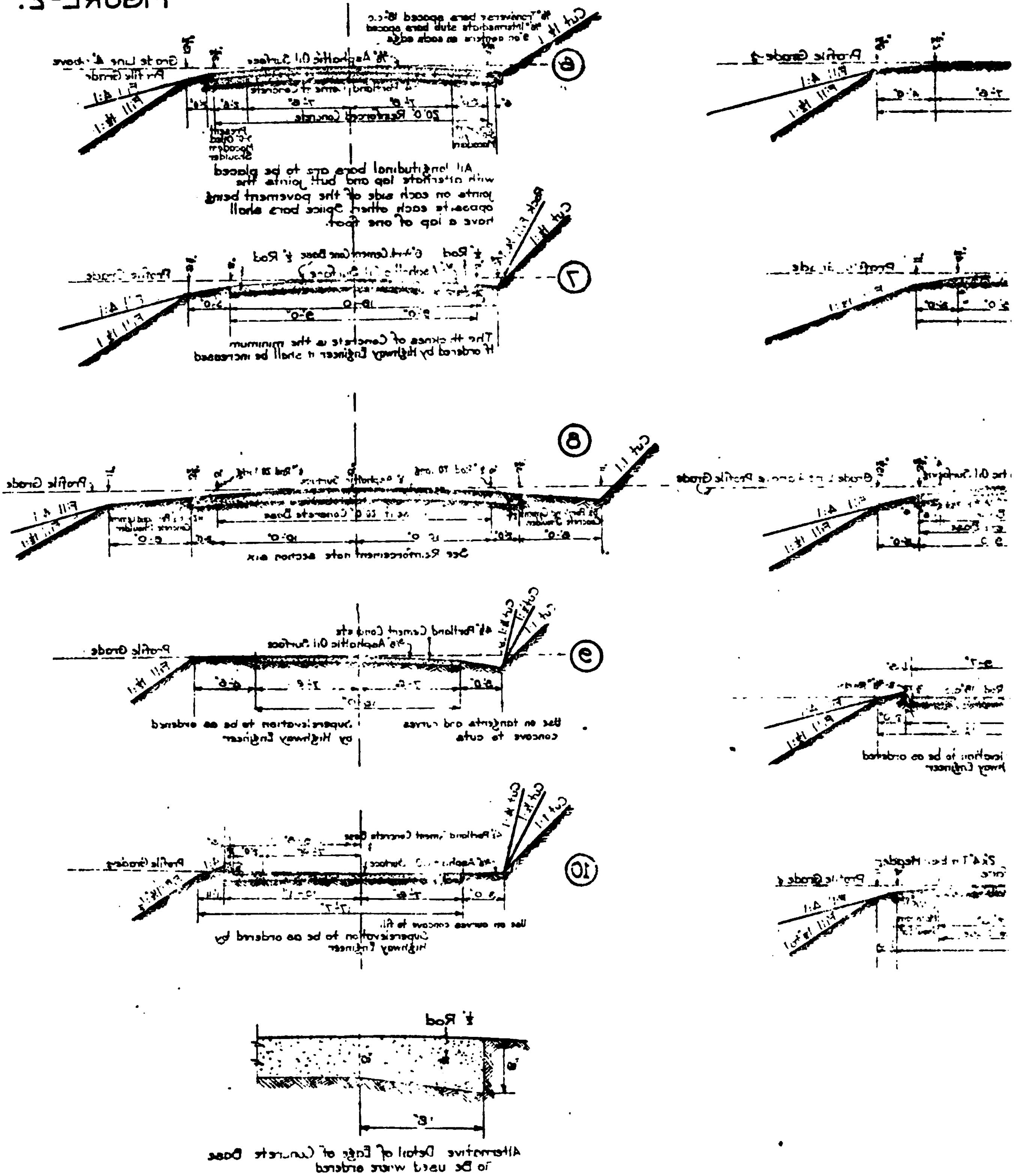
Pavement Crowns 5.13

The present tendency throughout the United States is for lower crowns on concrete roads. California remains one of the few states adhering to the somewhat obsolete practice of high parabolic crowns. This applies principally to the State highway system, as many of the individual counties in the State have, or are adopting lower crown sections where concrete construction is being used. It is to be hoped that the various communities will not go to the other extreme as is now being done in some instances. The very low crown, besides affording poor drainage, often has the appearance of a dished or concave surface when viewed in certain lights and shadows.

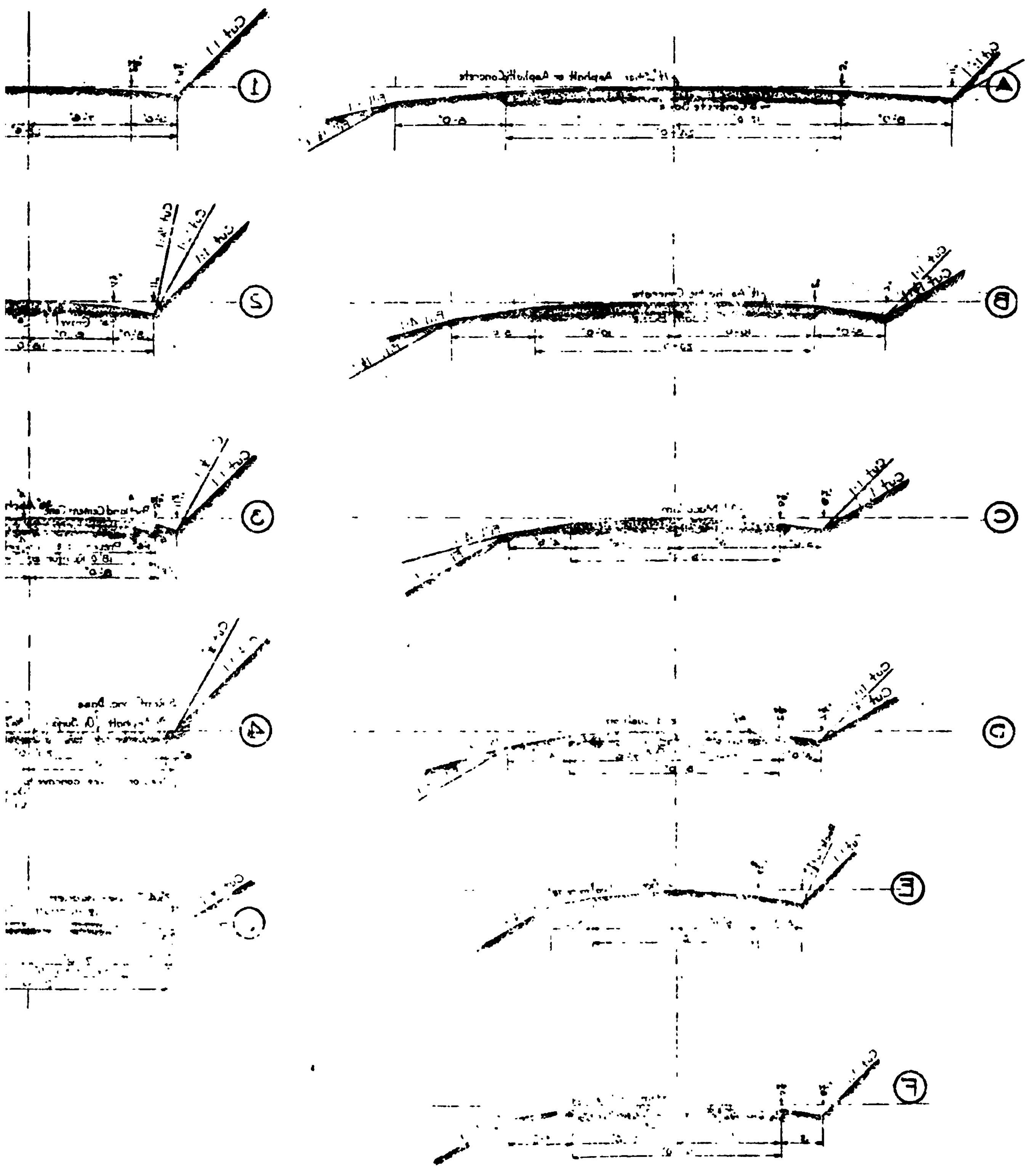
The primary object of a crowned roadway is, of course, to carry storm water quickly from the road surface to the shoulders and thence to ditches or drainage structures. Water collecting on any type of pavement when subjected to the hammering of traffic spells ultimate surface disintegration. A transverse gradient of 0.1% is ample for drainage purposes. Thus in a 20-ft. roadway, the required fall for the half-width would be $\frac{20 \times 0.1}{2} = 0.1$ ft. or 1.2 inches.

At present the generally accepted crown practice is from 1½″ minimum to 2″ maximum for a 20-ft. width of concrete roadway.

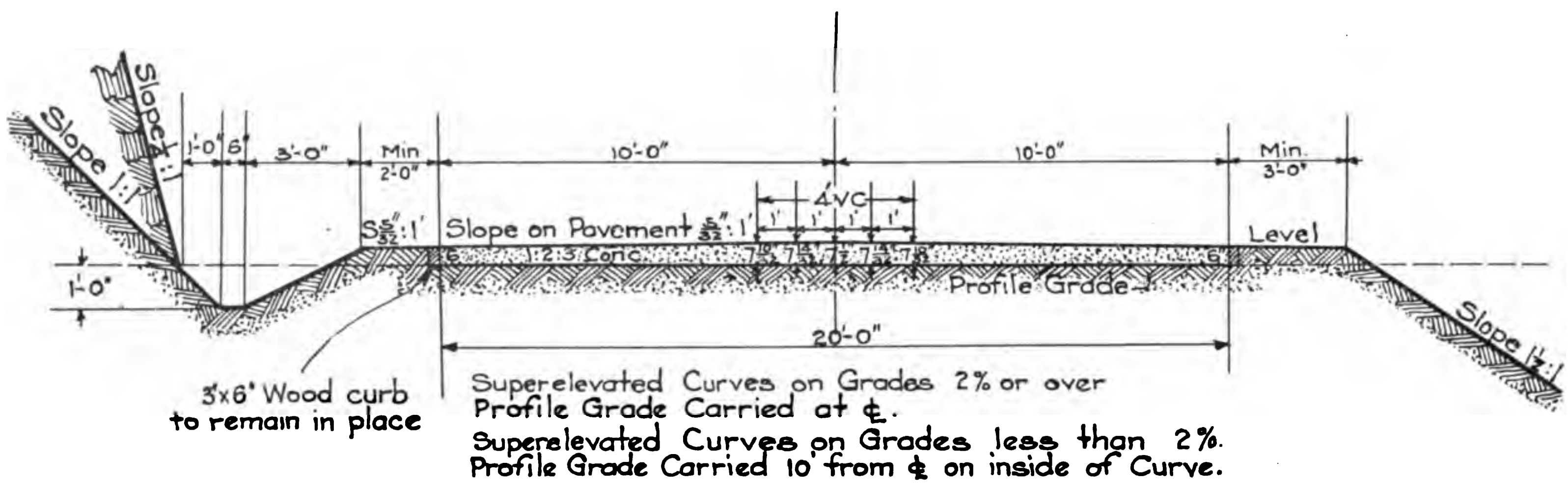
FIGURE-2.

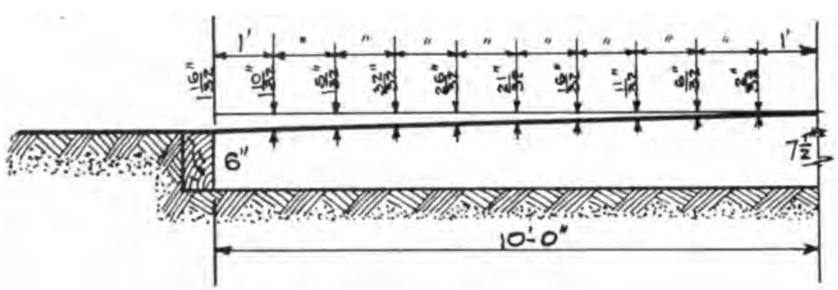


AL VIEWS—SPECIAL TYPES OF HIGHWAYS OF RECENT DESIGN



SECTIONAL VIEWS—TYPICAL HIGHWAYS PRIOR TO 1920.





HALF SECTION OF PAVEMENT

STANDARD 20 FOOT ROADWAY SECTION

ONE COURSE CONCRETE

STATE OF WASHINGTON

MARCH, 1919.

It is our belief that the State highway practice of high crown sections should be modified and that the maximum crown on an 18 or 20-ft. concrete road, should be 1½ to 2 inches, the parabolic or the straight line crown with 4-ft. vertical curve connecting tangents at the summit, being equally practical, modern and satisfactory.

Attached hereto are sketches showing the standard cross-section for concrete roads in California and Washington. One has but to ride over the Washington roads and note their uniformity and symmetrical lines to be convinced that our sister state is well advanced in the latest and most modern methods of design and construction.

The Improvement of Existing Grade Crossings 5.14

The neglect of grade crossings in California, so far as uniform paving construction and proper and efficient maintenance are concerned, is very marked. If grade crossings must remain with us until subways and overhead structures sweep them into the discard, **they should at least be properly paved and maintained** and uniform practice in such paving should be adopted.

It is noticeable on the State highways that about any class of construction is used to pave railroad crossings; ballast, oil-bound waste rock, oil macadam, and in some cases concrete and asphalt.

Where grade crossings must remain, due to unusual conditions, a permanent type of pre-cast concrete block with protected edges should be considered in conjunction with other paving types. Where concrete is poured on the job and regular train service maintained, the jar and vibration of moving trains is naturally detrimental to the green concrete, often causing rupture. The use of the precast blocks with some form of surfacing might eliminate such initial failure to a marked degree.

With any type of paving, it is a prerequisite that the tracks be heavily ballasted and that guard rails be bolted to tracks with proper spacers.

A successful crossing in Santa Clara County consisted of 14 inches of ballast, well tamped and subsequently grouted. Concrete paving was then placed to within 1½ inches of the proper grade and a 1½-inch Topeka surfacing subsequently added.

It is believed that instructions to all Divisions, covering a design that has proven successful should be issued by the Highway Commission and an attempt made to have maintenance crews reconstruct all uneven and rough crossings as early as possible, to this plan.

Experimental Roads 5.15

The necessity for experimental roads in connection with so large an expenditure as $73,000,000 on the State highways is apparent to anyone who has studied the road problem in California. This matter is taken up briefly under the caption, "Adobe and Clay Subgrades."

The safest, most practical and most convincing method of determining the value of various types, thicknesses and widths of roadway is to build a stretch of actual road and subject it to the elements and to traffic. This does not mean a stretch of 5,000 ft. of experimental road divided up into twenty or thirty intermediate sections of various types. Such experimentation has not added much to paving knowledge to date.

In this State it is possible to combine experimental roads with the regular construction program. In other words, the experimental road is not, strictly speaking, an experiment but a special type of construction built to meet the requirements of certain field conditions. The Highway Commission has adopted a certain type of concrete road of minimum depth. To experiment by building, say 5-mile concrete sections of various depths and richness of mixture with and without reinforcement, would be a logical construction program. These sections should be built in various parts of the state, particularly over clay and adobe subsoils; also adjacent to both medium and heavy traffic areas. The adulteration of adobe; the macadam or gravel foun-

dation; heavy plain concrete slab; thin slabs properly reinforced; slabs of uniform cross-section, and slabs thicker at the center than at the sides, and various other practical construction combinations should be used. The results obtained from this class of practical experimentation will prove invaluable in all future road construction in this state. Had the simple experiment of building various types of concrete road over adobe, with specially treated subgrades, been adopted in 1913 by the Highway Commission, a large waste would have been avoided and this problem (as already stated in a previous article) would be solved or, in any event, much less formidable today. It will require but a few years to demonstrate the actual value of the various experimental road types; will entail but little additional expense over the regular program and the numerous specially built units coupled with diversified subsoil and climatic conditions found in this State will allow of a more general study under not only the best but also the most severe conditions that can be found.

It is essential that every element entering into the construction of such experimental roads be tabulated at the time of construction and that the supervision be of a character as will assure known facts subsequently. Special maintenance accounts should be kept on each sectional experiment and all data carefully compiled. The resultant demonstrations and analyses after a period of years will then have some value.

The Automobile Association can assist this program by selecting certain sections in southern, central, and northern California for such experimentation and submitting this list to the Highway Commission with recommendations as to types of construction to be used.

6. WIDTH OF PAVEMENTS

Width of Paved Section 6.1

Under the caption, "Shoulders and Berms," certain economical and practical reasons are given for increased width of paved sections in California. Supplementing this with prevailing practice in the principal states of the Union, it can be said without fear of contradiction, that the tendency throughout the United States at the present time is for a wider section of paved roadway than has hitherto obtained.

For a number of years past, it has become more and more apparent that the 15-ft. width of paved roadway is insufficient to meet the requirements of a rapidly increasing vehicular traffic. The advent of the fast moving auto-stage lines, coupled with heavy motor truck traffic, is making the 15-ft. paved roadway anything but a safe place for the average automobile driver. A concrete example is found in Alameda County through what is known as the Altamont Pass into the San Joaquin Valley. The numerous auto stage lines running on schedule time require ample passing room at the speeds maintained and on week-ends and holidays the congestion is marked and the danger of accident great. This same condition is noticeable wherever adjacent to the large centers of population in California.

Under the rapidly changing conditions of the present era, a 15-ft. width of paved road in a new district becomes obsolete in a few years and must be widened out to keep pace with traffic progress. That such is the case in California today is evidenced by the policy of the State Commission in widening out or rebuilding to a greater width, certain sections of the State road system.

It would, of course, be an unwise policy to lay out a standard width of paved road for any and all conditions; a road as narrow as eight feet with occasional turn-outs may be ample for the needs of the Salton Desert country and may remain so for many years. A twelve-foot paved width of road into the foothills of Placer County, where natural decomposed granite shoulders remain hard and compact and require only moderate maintenance to keep in A-1 condition, is an economically sound width of pavement. Thus, many light traveled sections of the State highway system are, or can be, amply provided for by narrow widths of pavement.

But on the main trunk highways, irrespective of the volume of traffic today, it is a wise and farsighted policy that takes into account the future needs. A fifteen-foot section of paved road may be ample to meet the present traffic needs in certain sections today, but with the completion of the many county highway systems now under construction and the State laterals, feeders and new additions, the increased traffic in a few years will be such as to tax to capacity a road of such limited width.

It is noticeable that even with light travel, the tendency of many careful drivers of machines is to give the "other fellow" a wide berth and this very caution in passing often results in accident due to low or poorly maintained shoulders or the looseness of the shoulder material itself.

Consideration of the ever increasing commercial truck traffic dictates a width of road that will allow of ample passing room on the pavement proper without recourse to the dirt shoulder. With truck bodies, including overhang, measuring up to eight feet in width—allowing one foot passing room for two such trucks—an eighteen-foot road would be none too wide. In addition, the effect of such passing on the eighteen foot road subjects the edges of the road slab to undue stress and is a prolific cause of shoulder breaks and consequent initial road failure. Heavy wheel load concentrations do the least damage when the loads are in a position on the slab to secure a maximum distribution. It is obvious that on a narrow road, where wheels are crowded to the edges of the pavement, distribution of load must be greatly reduced and hence higher stresses within the structure obtain.

In this same connection, a quotation from the recommendation of the Committee on "Reconstruction of Narrow Roadways of Trunk Highways" of the American Road Builders' Association is also of interest:

"—the paved surface of the roadway on trunk highways should be **at least** twenty feet in width. For each additional line of traffic nine feet more should be added."

As already stated, the tendency of the times is for wider and safer pavements and as ample precedent convincing in its scope is found in every State in the Union, there is apparently no logical reason for this State to confine its major paving width to so narrow and dangerous a road section as fifteen feet.

In the third chapter following, road widths in California are discussed on the basis of ultimate expenditure. This cost analysis is the determining factor; its findings are sound and based on actual expenditures on the fifteen-foot roads of the present State highway system.

Our investigations and experiences therefore convince us that the wider paved road is not only necessary for future traffic requirements and backed up by overwhelming precedent, but that it is economically sound from every standpoint of financial outlay.

It is our belief in order to meet the future needs in California, a minimum width pavement of twenty feet on main trunk lines and of eighteen feet minimum on principal laterals between the main trunk highways should be adopted. The outlying roads or feeders traversing the thinly populated districts, or the purely scenic roads subjected to light travel the greater portion of the year, would better be left to an open policy rather than a stated program—the width of pavement being determined in the usual way, by study of the present and possible future traffic conditions.

Widths of Pavements on California Highway System and Comparison with Other States 6.2

By reference to Table II it will be seen that the generally adopted width of pavement in California (with a few exceptions near the large cities) has been fifteen feet.

The inadequacy of this width of pavement from a traffic standpoint has already been discussed and it seems advisable to enter a comparison with practice in other states as an exemplification of present tendencies in this direction.

It must be remembered in considering traffic in California that this State ranks fourth in the United States in total number of motor vehicles registered in 1919 and that when comparisons are made with such States as Ohio, Pennsylvania and Illinois, it is with States having relatively similar motor vehicle travel on their roads. The variation in numbers of motor vehicles in these three States and California did not exceed 20,000 in 1919 and the motor vehicle registration of each in 1920 will closely approximate 600,000.

Practice in these states is, therefore, of considerable value for comparison with that in California.

Minimum widths on state trunk lines are as follows:

Ohio	18 and 20 feet
Illinois	18 and 20 feet
Pennsylvania	18 ft.

All three States have some mileage of sixteen-foot roads mostly confined to secondary routes.

In regard to practice in other states it may be stated that of thirty-five states from which data has been obtained, twenty-eight show a greater **minimum** width of pavement than California, the prevailing practice being a minimum width of eighteen feet with a tendency, at this time, to increase the minimum width to twenty feet on all trunk lines.

Original State Highway Program of Shoulder Construction 6.3

It was recognized by the Highway Commission soon after the first fifteen-foot roads were built that this paved width was, in general, too narrow for the rapidly increasing traffic that quickly followed in the wake of the road improvement, and an early effort was therefore made to increase the width of road on the main trunk highways by building oil macadam or gravel shoulders, 2½ to 3 ft. in width, on each side of the concrete, thus providing a 20 to 21-ft.

width of paved surface. As early as 1913 an ambitious program, which was given wide publicity, was laid out. Generally speaking, it contemplated the rock-shoulder method of widening the entire road system. A number of sections in various divisions of the State were improved in this way.

The experienced engineer realizes the difficulties that must be surmounted in order to build an oil-macadam shoulder as narrow as three feet adjacent to a concrete roadway. Special skill and experience is necessary in this type of construction, and assistants and working organization capable of securing first class results cannot be picked up at random. To build oil-macadam shoulders that will not show settlement at the construction joint; that will wear uniformly and not develop waves, corrugations and pot holes and, at the end of a period of five or six years under traffic, prove equally as good as the adjacent concrete pavement is, generally speaking, not being done and it is doubtful if such a result can be obtained even under the most ideal conditions.

The rock-shoulder experiment by the State organization proved more or less unsatisfactory from both an economical and structural standpoint and finally fell into disuse except in isolated cases where a sealed shoulder was necessary to meet unusual conditions.

Apparently, due to the abandonment of the macadam or gravel shoulder method of widening out the fifteen-foot concrete roadways, the original ambitious scheme for wider roads, as proposed by the Commission seven or eight years ago, drifted into obscurity and due to an apathetic public was never resurrected. It is apparent that the mere failure of one class of construction to give the results desired should have in no wise disrupted the original plan of widening. The addition of concrete shoulders similar to the paved section adjacent could have supplanted the proposed oil macadam years ago. For the past several years just such a method of shoulder construction and widening has been adopted and is still being followed. Had a comprehensive and logical yearly program of widening—based on budget allotments worked out and conscientiously adhered to—been adopted, the Commission's original program would have been well advanced, if not completed, at this time.

It is apparent that numerous excuses for abandonment of the original widening program can be made, such as lack of funds, bond market, other more necessary construction, etc., but the fact remains that the people were promised these wider roads years ago; they have not materialized to date in the face of repeated new bond issues and more ambitious road construction.

Relative Economy in Extra Width of Concrete Pavement by Comparison With Rock and Oil Shoulder Construction 6.4

The general features controlling this analysis are:

1. Relative life of rock and oil shoulders.
2. Cost and maintenance of rock and oil shoulders.
3. Cost of extra width concrete pavement.

It is a primary fact that the construction of paved shoulders on permanent highways is a development necessitated by traffic requirements for a wider travel way. In this state it was probably in the attempt to make an inadequate highway fund cover a large mileage of paved road that the policy of narrow permanent pavement with rock or rock and oil shoulders was adopted, as it was planned to draw from the maintenance fund largely for shoulder work.

An inspection of the several hundred miles of these shoulders constructed from three to six years ago, warrants the statement that with little exception the end of their economic life has already been reached. Further than this, many miles of former rock shoulders have already been replaced by shoulder strips of concrete, after only three and four years' service. Considering the two factors it is probable that the average life of this type of shoulder, when

used as in California mainly to provide traffic way, is not to exceed four years without excessively costly repairs or virtual replacement.

The character of shoulder improvement varied greatly with location of highway but a large portion of the work consisted in a typical four-inch macadam construction with oiled surface. Numerous reports on cost of this work performed in 1915 and 1916 show a variation ranging between $1,350.00 and $1,600.00 per mile in general. Light work with shoulder strips approximately two feet wide has been accomplished for as little as $800.00 and $900.00 per mile, while heavier work (six inches of rock) and wider shoulders (three feet each) with all surfacing, has entailed an expense as high as $3,200.00 per mile.

Table XV following gives in detail the cost of shoulder improvement and maintenance charges on numerous sections of State highway built in 1914 and 1915 where work varied from simply oiling sand or loam shoulders to excellent macadam construction with bituminous surfacing. These sections having the longest life are used as furnishing the most complete data.

It is determined from tabulations already given that the average cost of concrete pavements constructed prior to January, 1916, was $6.33 per cubic yard in place.

To have constructed the original fifteen-foot pavements to greater widths would have entailed the following costs:

To 18 ft. in width	$1,238.00 per mi.
To 20 ft. in width	2,064.00 per mi.

In view of the standard cross-section of grading adopted by the State (21-foot width in cuts and 24-foot on fills) no extra costs would have been added to the above, for grading.

It is apparent that an increase in width of pavement to 18 feet would have been a positive saving in first cost of construction over the rock shoulder program.

It will be seen from Table XV that in several sections an increase in width of pavement to 20 feet would also have entailed a less first cost.

When we add to this first cost the difference in maintenance over the period following completion, it can be stated that the majority of these sections as shown, represent a greater cost at the present time than would have followed the construction of the 20-foot concrete pavement originally. (Cost for extra 5′ width.)

Finally, when it is found that on some of these sections the rock shoulders have been replaced with concrete and of the remaining rock and oil shoulders 75% are in need of such replacement, there is no need of further comparison from the cost standpoint.

The economy in designing pavements of sufficient width to satisfy traffic conditions is further borne out by an examination of maintenance costs where it is possible to find two widths of pavement under similar traffic. One of the best examples for this purpose is found in the two adjoining State highway sections south of Fresno—Sections 4-A and 4-B, Fresno County; one, a fifteen-foot pavement, the other a twenty-foot pavement. Both of these sections are subjected to heavy traffic; Section A approximately 3,000 and Section B approximately 3,500 vehicles daily during the fruit season.

On Section A, 15-foot pavement, total shoulder costs to date have been $15,821.27.

On Section B, 20-foot pavement, under heavier traffic, total shoulder costs to date have been $1,398.47—a difference of $14,422.80 in six years.

Similar examples exist in Santa Clara, San Bernardino and Los Angeles Counties, where direct comparisons can be made.

It seems to the writers that the facts in terms of the expenditure of highway funds are clear and incontrovertible and, aside from all other considerations, ultimate economy in miles of highway to be built point to the necessity for proper width of pavement to accommodate the traffic.

SHOULDER MAINTENANCE & IMPROVEMENT

SECTIONS OF HIGHWAY COMPLETED IN 1914-1915

TABLE XV

DIVISION COUNTY & SECT.	LGTH.	TOTAL MAINTCE. TO JUNE 30 1920	PER MILE PER YEAR	NON PERMENANT IMPROVEMENT TO JUNE 30 1920	TOTAL EXPENDITURES TO JUNE 30 1920	REMARKS.
IV ALAM. 5 A	10.86	9628.26	177.31	14170.24	23798.50	
V S.L.O. 2 D	6.37	5326.12	167.21	9156.67	14482.79	
V S.L.O. 2 E	13.42	5385.24	80.25	1179.51	6564.75	
V S. B. 2 A	5.81	3084.48	106.18	11889.09	14973.57	
VI KERN 4 F	12.45	1611.57	25.89	1993.44	3605.01	
VII L.A. 2 C	11.28	1455.63	25.81	5702.45	7158.08	
VII ORA. 2 C	7.40	4794.90	129.58	15209.12	20004.02	
VI FRE. 4 A	8.21	2404.21	58.58	13417.06	15821.27	$8861 OF AMOUNT SHOWN WAS EXPENDED IN 1918 FOR 1.8 MILES OF CONCRETE SHOULDER.
III STAN. 4 A	12.04	2784.32	38.55	12209.27	14993.39	6 MILES OF CONCRETE SHOULDER CONSTRUCTED IN 1919 COST APPROXIMATELY $48,000
III STAN. 4 B	9.58	2101.05	36.55	6787.74	8888.79	
IV S.M. 2 A	10.32	5385.86	86.98	4444.00	9829.86	
IV S.CL. 2 B	17.30	2695.98	25.98	12526.52	15222.50	4 MILES OF SHOULDER CONSTRUCTED IN 1920 COST $30,138
VI KERN 4 D	10.14	1600.26	26.30	4670.76	6271.02	
VI FRE. 4 C	9.56	1901.07	33.14	3860.95	5762.02	
VI MER. 4 C	10.86	2509.21	38.51	5542.11	8051.32	
VI MER. 4 D	9.74	1193.07	20.67	3384.86	4577.93	
VII L.A. 2 B	10.13	1527.35	25.12	1457.04	2984.39	
VII L.A. 2 A	6.55	1479.36	37.64	19904.28	21383.64	
VII ORA. 2 DEF	11.16	977.21	14.59	14589.35	15566.56	
VII S.BD. 19 AB	6.61	986.33	24.87	1560.96	2547.29	

NOTE:- COMPLETE SHOULDER IMPROVEMENT DATA DOES NOT APPEAR IN THIS TABLE AS A CONSIDERABLE MILEAGE OF MACADAM AND GRAVEL SHOULDER WAS CONSTRUCTED IN CONJUNCTION WITH CONTRACT WORK AND THEREFORE WOULD NOT APPEAR IN MAINTENANCE RECORDS.

Shoulders and Berms 6.5

Based on a personal inspection of the California State highway system, it is our opinion that one of the great sources of weakness and the incipient cause of numerous road failures **is the almost uniform neglect of shoulder maintenance.** This neglect was found in every division of the State to a greater or less degree. Naturally, some divisions were better than others, depending upon the Division Engineer, the efficiency of the repair gangs and maintenance patrol system, coupled with the funds allotted. Hundreds of miles of shoulders adjacent to the old 4-inch concrete base and the newer and thicker sections **showed such universal neglect as to be astounding.** The crushing of concrete in small segments along the unsupported shoulders and the gradual breaking back of the base from the weakened area is a matter of no small moment.

On many of the 15-foot road sections, neglect of shoulders has left an abrupt drop at the edges of the pavement, often to the full depth of the concrete. The danger to the traveling public is therefore tremendously enhanced and many bad accidents have already occurred throughout the State which can be traced directly to this source.

Again, for the proper protection of the concrete road in place, this lack of maintenance means serious economic loss and high, increased maintenance costs. The low shoulder acts as a rut or channel for much of the storm water falling in the winter on the crown of the road. This water, working down and under the base, permits a partial or complete saturation of the subgrade, weakening its supporting power and causing settlement, cracking, breaking down and disintegration of the road slab. **Neglect to guard against such a contingency can only be defended under conditions of a completely depleted maintenance fund and, in any case, the assignment of maintenance allotments should anticipate such a grave problem and prepare in advance to meet it.**

The present method of shoulder maintenance is undoubtedly inefficient and wasteful. In some sections a loose sand shoulder is thrown up against the concrete base with no means of binding the material together. In other sections, the blade throws up a dirt shoulder and it is then left to fight out its own salvation. Sprinkling and rolling such a shoulder do little or no good unless the sprinkling is continued regularly, and such costly maintenance on the State system is more or less prohibitive. In consequence, the traffic, turning out onto the shoulders, soon pulverizes the surface and the dirt blows away. This loss of earthy material is becoming a problem in some sections at this writing and, unless a more up-to-date method of shoulder repair and maintenance is adopted, deep, unsightly burrows on the right-of-way will take the place of the present slopes or the State will be compelled to haul shoulder material from outside sources at heavy cost.

The loose gravel method of shoulder construction serves a purpose: it keeps the traffic on the concrete highway, as few drivers care to turn out onto a pile of loose, shifting road metal unless forced to do so. The same applies to macadam, shale and other material of rough, irregular cleavage, so commonly used to repair the State Highway shoulders. It is faulty in that it allows the water to pass through the porous non-compacted shoulder and soften both shoulder and subgrade adjacent.

It is our belief that the best and most economical shoulder is that secured by increased width of concrete pavement, as demonstrated in article 6.4, preceding. Except immediately contiguous to the large cities, a 20-foot roadway is of ample width for general traffic and does not necessitate turning out upon the adjacent earth shoulders. This is being demonstrated in a most thorough and practical manner in every section of the State where wider roads have been built. When the traffic is kept off the shoulder **nature soon takes charge of the maintenance of the roadsides by carpeting and protecting the earth shoulders with grass or other vegetation.**

It is our suggestion that your association recommend to the California State Highway Commission a possible solution of the shoulder problem; that the methods adopted by the French Engineers be considered—i. e., the building of a berm adjacent to every road slab, thus the road takes on the slight appearance of being always in cut. This method, with the widened concrete road of 20-foot minimum, will, to a large extent, solve the shoulder maintenance problem.

In the State of Washington where such a wide section has been adopted, the minor amount of shoulder maintenance due to heavy growth of vegetation carpeting the shoulders is particularly noticeable even in the absence of a protecting berm to discourage traffic from turning out and on to the shoulder proper.

With a berm of the type suggested it will, of course, be necessary to carry drainage off the roadway at certain points by small transverse ditches. With frequent drains of this type, no accumulations need occur; hence, scour of shoulders can be avoided. But, in the case of vertical curves on fill sections it will, of course, be necessary to provide inlets and flumes at the low point—a most workable and economical method of protecting heavy fill sections. Thorough cuts make good natural drains when paved full width, diagonal ditches, paved gutters or flumes being used where the cut runs out.

The berm or shoulder of heavy clay and adobe sections may require special treatment, such as the introduction of gravel, shale, crushed rock or other material; surface treated with heavy asphaltic oil (85% to 95% bitumen) to act as a seal coat and keep the water out, thus somewhat regulating moisture content of subgrade along the pavement sides—a common point of failure on adobe subsoils.

The sandy soils of the Imperial Desert, San Joaquin Valley and some coast sections are naturally the greatest problem. No berm of this material will stand and, in some cases, the wind alone will cause shifting of the shoulder material without the aid of traffic. It is, however, obvious that the wider concrete section will keep traffic off the shoulders, and with the propagation of vegetation or plants that thrive in drifting dunes, eventually the sandy shoulders will be carpeted and protected.

The use of the lighter gravity road oils in conjunction with sand can be successfully worked so as to produce a good, firm shoulder. However, this type of shoulder soon goes to pieces if subjected to continuous or heavy traffic and, if used, it should be constructed only in conjunction with the 20-foot concrete road, thus reducing shoulder traffic to a minimum.

7. BITUMINOUS AND ASPHALT SURFACING

Bituminous Surfacing 7.1, 7.2, 7.3

Two types of bituminous surfacing are in in general use by the Highway Commission:

1. A thin bituminous carpet composed of heavy asphaltic oil, or high penetration asphalt, and broken stone screenings—average thickness of surfacing slightly under one-half inch.

2. A so-called Topeka mixture composed of medium penetration asphalt, pulverized limestone, graded sand, and small-size broken stone and screenings—average thickness approximately one and one-half inches.

Examination of the data on hand shows the following amounts of the two types of surfacing to have been laid on concrete base up to June 30, 1920:

Thin bituminous carpet . .	5,201,000 sq. yds.
Topeka mixture and asphalt	781,000 sq. yds.

Other types of bituminous surfacing laid in small and presumably experimental amounts include the following:

1. Sheet asphalt (without binder course).
2. Willite (a plant-mixed asphaltic surface to which is added copper sulphate).
3. Bitucrete (a thin bituminous carpet similar to that in general use but in the construction of which the screenings and sand are spread hot).
4. Mastic (plant mixed asphalt and lime carbonate).

While the costs and maintenance of these surfacings appear in tabulations of pavement costs, the figures are not in the detail that will be undertaken here. Before proceeding with such cost analysis, some description of the two general types will be undertaken.

Thin Bituminous Carpet

Only two materials enter into the construction of the bituminous carpet—broken stone screenings and either heavy asphaltic road oil or high penetration asphalt. Extremely coarse sand or pea gravel has been substituted for the broken stone screenings for some of the work, but the preferred practice lies in the use of broken stone screenings. Up to within the past year, practically all of this surfacing was constructed of heavy asphaltic road oil and screenings, the latter passing a circular screening opening ½-inch in diameter and from which substantially all fine dust had been removed. The more modern practice is to use a grade "E" asphalt and both ¾-inch and ½-inch broken stone screenings.

The work consists in spreading the hot asphalt under pressure, by means of power-driven trucks, in two coats of ¼-gallon each per sq. yd. of surface, covering each coat after its application with a thin layer of screenings. A prerequisite to the work is a thorough brooming and cleaning of the concrete surface before the first application of asphalt is made. Portable and semi-portable heating plants are utilized to bring the asphalt to a temperature varying from 350 to 400° F., so that this material reaches the pavement at from 250 to 350°.

In the early work of this character little or no attempt was made to roll the screenings into the asphalt, but with the use of coarser rock the practice is to follow the spreading of the screenings by a light rolling.

The equipment necessary to apply this wearing coat is made up on the average as follows:

1. Semi-portable (or stationary) road oil or asphalt heating plant.
2. Two or three motor trucks with power dump bodies, one of which is equipped with a 1,000-gallon pressure oil distributor.
3. One horse-drawn street sweeper.
4. A set of car unloading chutes or a portable bunker.

5. Small tools such as round and square point shovels, broad-bladed hoes, fibre and steel stable brooms, etc.

With such an outfit and a crew varying in size from fifteen to eighteen men, with a two-horse team for the sweeper, approximately 2,500 to 3,000 sq. yds. of completed surfacing is laid daily.

Average costs on a large amount of this work performed in 1914, 1915 and 1916 is summarized in the following table:

AVERAGE COSTS

	Per Sq. Yd. of Pavement
Unloading screenings	\$0.0035
Hauling and piling screenings	0.0130
Spreading screenings on oil	0.0037
Unloading tank cars and heating oil	0.0056
Hauling and spreading oil	0.0050
Cleaning surface to receive oil	0.0040
Screenings (cost f. o. b. cars R. R. sidings)	0.0325
Asphaltic oil (cost f. o. b. cars R. R. sidings)	0.0142
Interest and depreciation	0.0045
Supervision and overhead	0.0025
Total cost per sq. yd.	\$0.0885
Approximately 1 cent per sq. ft.	

Under present-day prices, including an increase from one-half gallon to approximately six-tenths gallon of asphalt, together with the extra cost of rolling, the cost of applying this surfacing should be approximately sixteen cents per square yard.

The thin bituminous top as applied to the State roads has proven an economical and efficient type of low-cost topping under certain conditions of traffic and loadings. In the fruit hauling districts of the Santa Clara and San Joaquin Valleys, the surface can hardly be classed as a success due to continual stripping and excessive maintenance. In the light traveled districts where the auto rather than the truck predominates, such as along the Coast Highway between San Juan Capistrano and San Diego, San Miguel and San Luis Obispo, and in the sparsely settled sections in the San Joaquin Valley between Fresno and Turlock; also outlying districts of Los Angeles, Orange and Ventura Counties, are found some of the best examples of this type of surface. A comparison of its present condition, age and history of upkeep is, in each instance, sufficient to convince the average engineer that this wearing surface—often criticised, ridiculed, and labeled as a failure—is on the contrary very much of a success when used with reserve and judgment under the moderate traffic conditions that such a low cost type of thin asphaltic surface should reasonably be expected to withstand.

Topeka Mixture

In general, the California Highway Commission has secured good results with its asphaltic wearing surfaces. As the greater portion of the work of this character has been limited to the so-called Topeka mixture, this discussion refers particularly to that type of surfacing.

The grading used is along the lines of standard sheet asphalt in so far as filler and 10 to 200 mesh material are concerned. The mixture carries a maximum of 35% of ¼-inch to ½-inch broken stone with a bituminous content running as high as 10% maximum. This is not the true Topeka mixture, but a modification. The origination of this specification is credited to Mr. A. E. Loder, former Division Engineer of the Highway Commission.

Methods of laying, typical plant, equipment and crew, do not differ from the practices in general use and these are too well known to need further description here.

The application of one and one-half inches (after compression) of this surfacing directly to a concrete base without the use of the regulation binder course was a new departure from standard paving practice when first adopted by the California Highway Commission; today it is in more general use, due to satisfactory service.

A paint binder course composed of asphalt and distillate in the proportions of one part by volume of asphalt dissolved in 1½ parts of 50 to 55 degree (Baume) distillate, has been used on a portion of the work in California. In examining surfacing laid with this paint binder coat, it is found that an excellent bond between the asphaltic mixture and concrete obtains. However, the value of such a binder course in this work is a question that has not been sufficiently developed to warrant conclusions either as to its necessity or advisability from the expenditure standpoint.

The general average condition of the majority of these surfaced highways is good and speaks well for the work of the Commission. Much of the success is attributed to the good work of the Commission's testing laboratory at Sacramento, to very rigid plant control of mixture and to efficient methods of field inspection.

The condition of the Topeka surface 1½-inch in thickness laid on water-bound macadam on the Foothill Boulevard in Alameda County and on sections down the Peninsula between San Francisco and San Jose speak for themselves. Their age varies from six to seven years; they have been subjected to the heaviest main trunk travel and their condition today would lead to a forecast of a considerable additional life. Maintenance costs have not been excessive; for example, the maintenance cost on three sections on the San Francisco Peninsula average approximately $119.00 per mile per annum.

The numerous dry seasons in California for the past few years may have much to do with the efficiency of this type of construction. Rising ground water has been known to accomplish its destruction in a few seasons. It will be interesting to note the condition of these pavements after several consecutive heavy, wet seasons.

Cost Analysis of Thin Bituminous Carpets and Topeka Mixtures in California

As explained in detail elsewhere in this report, it is our belief that the ultimate worth of any pavement—and this applies also to pavement surfacing—is its ultimate cost for service rendered.

Due to the fact that the greater portion of the more recently applied surfacings of both the thin bituminous tops and the asphaltic mixture have been utilized primarily in the maintenance of the distressed concrete sections in an effort to prolong the life of such pavements, the cost analysis of either type is directly involved with the analysis of concrete pavement. However, sufficient amounts of both types of surfacing were laid in the early days of the work to permit an accurate development of their final cost to the period of economic life of the base itself.

We have found by analysis that the average life of the thin concrete base constructed prior to January 1, 1916, is about eleven years. It is logical to assume that bituminous surfacing constructed in the same period will afford the best illustration of the economic worth over a period of years, inasmuch as more comprehensive maintenance costs can be obtained on such surfacings.

Table XVI following is a comparison at the end of a life of twenty-five years (the average bond life) between the costs of thin bituminous carpet and Topeka surfacing. The difference in final cost is so marked as to warrant even a more general use of the thin bituminous top under conditions of moderate traffic providing the pavement requires surfacing.

Maintenance curves from which the average economical life of the two types of surfacing is derived are attached to Table XVI.

TABLE XVI

COMPARISON OF ULTIMATE (25 YEAR) COSTS
THIN BITUMINOUS AND TOPEKA SURFACING

TYPE	INITIAL COST OF SURFACING INCL. ENGRING } AVE. MILE	INTEREST TO END OF AVERAGE BOND LIFE	ECONOMIC LIFE IN YEARS	TOTAL MTCE. TO END OF ECONOMIC LIFE	RECONSTRUCTION COST	INTEREST TO END OF BOND LIFE	MAINTENANCE	FINAL COST OF SURFACING
THIN BITUMINOUS SURFACING	$796.42	$995.53	7	$564.30	*$5124.00	$4739.70	$1298.70	$13 518.65
TOPEKA SURFACING	$4550.00	$5737.50	13	$2320.00	$8712.00	$8494.20	$2950.00	$32.763.70

Reconstruction of surfacing must take place after eleven years which is economical life of pavement base.

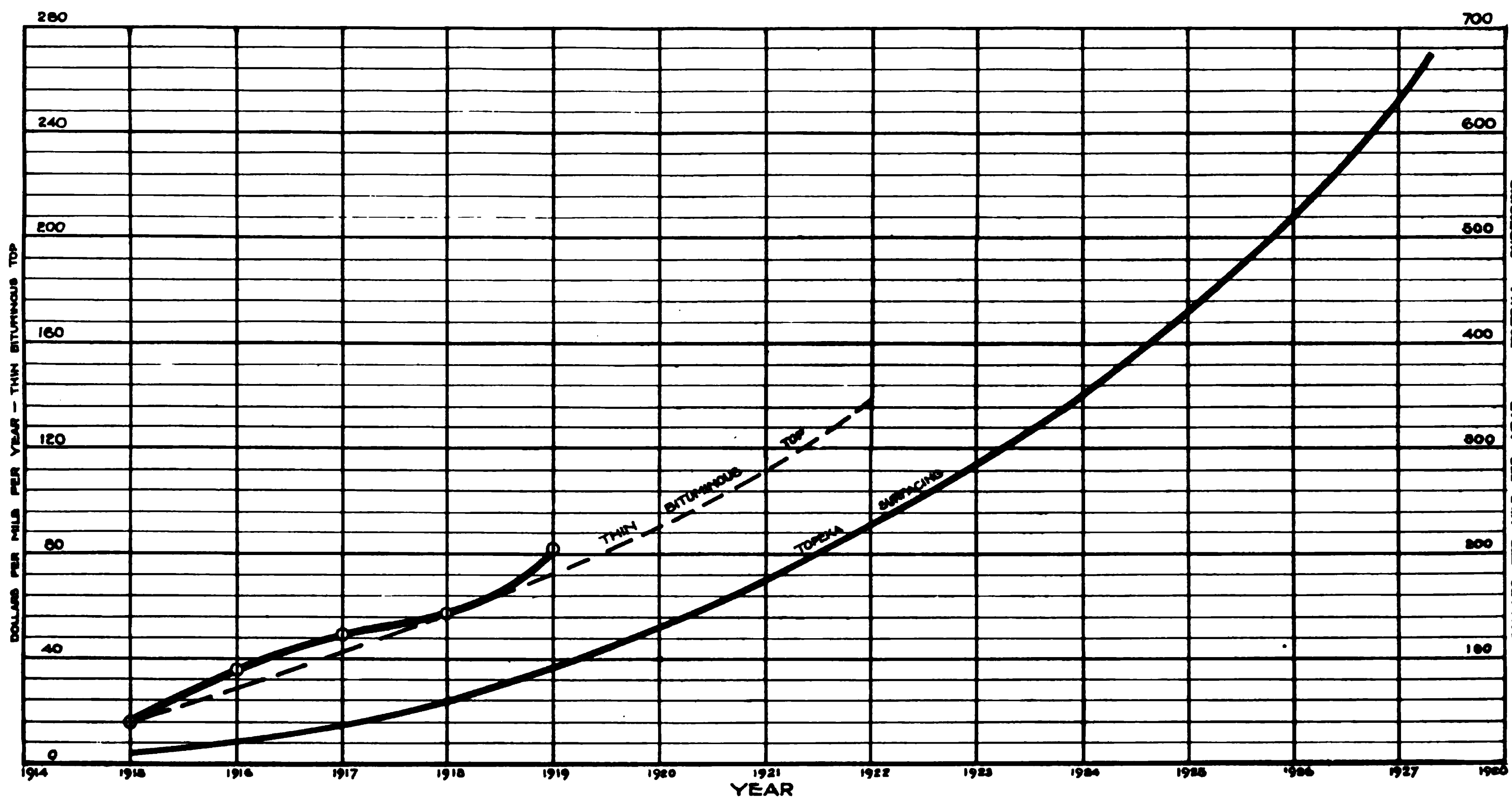
* Thin bituminous surfacing reconstructed at 7, 12 and 19 year periods.

Maintenance costs are taken from maintenane curves on Figure 3 following.

FIGURE 3

MAINTENANCE CURVES

THIN BITUMINOUS TOP AND TOPEKA SURFACING
TO END OF ECONOMIC LIFE



Slipperiness Due to Asphaltic Wearing Surfaces 7.4

Steadily increasing rubber-tired motor vehicle traffic is rapidly thrusting to the front many new and formidable road problems for solution. One of the latest that gains impetus in a state or community through loss of human life and consequent awakened public opinion, is the slipperiness of various types of road surfacing in damp or wet weather.

In the States of Oregon and Washington, where long rainy seasons are quite common, many of the main highways are posted with danger signs calling attention to the slipperiness of the pavement surface. In Washington the statement is made by numerous county road commissioners and engineers that the list of fatal accidents due to this cause in the past few years has compelled the authorities to seek a permanent solution of the problem. Apparently the construction that meets popular approval and endorsement by the motoring public in the above state is an unsurfaced concrete road. This is due to the greater frictional resistance of the average concrete surface when compared with oil or bituminous macadams; or other types of penetration or plant mixed wearing surfaces.

It is a matter of common knowledge that all asphalt surfaces are more or less slippery and hence dangerous in wet weather. In past years when motor vehicle traffic was moderate this condition, while still obtaining, was less noticeable. The principal paved areas lay within the confines of municipalities and slower speed and fewer rubber-tired vehicles reduced the casualties to a minimum that was not alarming. With the completion of thousands of miles of State and county highway systems embodying nearly every conceivable class of construction and type of wearing surface; with the excessive speeds and tremendous increase in motor vehicles, it is small wonder that the question of slipperiness is today becoming a most formidable problem and one that must be solved in the interest of life and limb. In California, this question is of more serious moment in the northern and middle portions of the State than in the south; it is a matter of rainfall coupled with the number of days over which the annual precipitation extends. In states where light rainfall predominates and in the arid regions, the problem is, of course, negligible.

The solution for slipperiness and consequent loss of life in wet weather probably lies in the selection of a true non-skid pavement. Plain, unsurfaced concrete more nearly meets that requirement today. An asphaltic wearing surface of very high rock content without the usual bituminous seal coat, is probably next in the order of non-skid qualifications, but this pavement surface will eventually "polish" to a marked degree through the action of rubber-tired traffic and oil droppings, requiring sanding or surface treatment to again restore its non-skid qualities. The common sense solution of the whole problem lies in slow and careful driving on wet and slippery pavements. A motor vehicle law with such restrictions would control the cause irrespective of the type or class of road. The practical enforcement of such a law, however, is yet to be worked out.

Necessity for Surfacing Concrete Roads to Prevent Wear 7.5

It is our opinion that the wear on the California Highway Commission's concrete roads is negligible. This is based on a personal inspection trip over practically the entire State system. Of the sections inspected, varying in age from one year to seven years under varying traffic conditions, only a very few sections show actual surface abrasion that could be considered as of importance, and in almost every instance an inspection of the concrete warrants the statement that frost bite, poor curing methods and similar conditions that produce inferior concrete surfaces are the chief factors that enter into the non-resistant qualities of these pavements when measured in the terms of abrasion due to traffic.

An inspection of the concrete roads of Washington and Oregon confirms the California experience. Pronounced abrasive action on concrete roads in these two states is almost nil. Yet, where occasionally found, the quality of the concrete is invariably poor and quite apparent from mere superficial inspection.

While no actual measurements have been made in any of these states, using instruments of refinement and precision, as now proposed by the U. S. Bureau of Public Roads, it is doubtful if such precise measurements and readings will be of any practical value due to the long period of time necessary to secure even one-quarter inch wear on a good concrete surface. Other causes of failure are too numerous and apparent and therefore of far greater importance than abrasive action.

As a concrete example of wear, Commissioner Edward N. Hines of Michigan reported in September, 1916, as follows:

> "Woodward Avenue road, the oldest concrete road in Wayne County, is now in its eighth year of service. It has carried an estimated total traffic of over 7,000,000 vehicles of all kinds from motor cars to heavy traction engines, and the wear on its surface has been so slight that it is difficult to measure. The usual estimate places this at from one-eighth to one-quarter inch."

From our investigations and observations of concrete roads in California and elsewhere covering a period of many years, we are of the opinion that a thin bituminous or skin-top wearing surface applied to a **first-class concrete road** is an unnecessary and unwarranted expenditure if its use is for the purpose of **preventing wear** or **abrasion of the concrete surface.** A well designed concrete road of high quality, honestly constructed and efficiently supervised, is one of the most attractive highways that can be built. If it is structurally right, it will require no surfacing and without such surfacing it will be less slippery and consequently a safer road for wet weather traffic.

If the same concrete road is not structurally right and develops numerous triangular breaks, long unsightly longitudinal cracks, radiating and transverse cracks of magnitude, shows excessive crazing of surface or much abrasive action, then the application of a bituminous wearing surface is not only warranted but necessary in order to protect the concrete surface from disintegration under traffic. The bituminous surfacing spreading uniformly over the cracked and broken concrete surface will not only preserve and prevent the cracks from raveling back but will lend itself to any new cracks that may appear, effectually sealing the surface. Probably the greatest benefit will be derived by the complete sealing of the surface, thus preventing the entrance of water to the subgrade with consequent danger of saturation. A road of this character from the esthetic standpoint would be improved 100 per cent in general appearance. All of which presupposes a concrete road not in a state of partial collapse or disintegration due to too thin a section or too lean a mixture; nor one poorly mixed, laid and cured; nor one being wrecked by traffic too heavy for the design. A road in this condition should unquestionably be rebuilt.

It presupposes surfacing the great, general average of four-inch concrete roads in California where traffic conditions are not excessive, subgrade conditions good, and present condition and history of the road such that an expenditure for bituminous surfacing will give added economical life to the roadway commensurate with the cost of such surfacing and preserve it against the disintegrating elements already mentioned.

Double Decking and Surfacing Old Concrete Roads 7.6

Two methods have been adopted by the State Highway Commission to prolong the life of concrete road sections on the State system that are breaking down badly under traffic or that are showing signs of a possible early demise, viz:

(a) Double-decking the old concrete road by placing a 4-inch slab of concrete on the original base, the same being reinforced with ⅜-inch steel bars spaced 18 inches on centers. Where old road is badly disintegrated and shattered, the entire area is taken up and replaced, thus securing a new section of concrete 8 inches in total thickness.

(b) Surfacing concrete base with $1\frac{1}{2}$ inches of Topeka mixture—an asphalt wearing surface of known value.

Double decking has been resorted to in many eastern states and in consequence is not new or original to California. Unfortunately, the work has not been extensive enough to permit of conclusive deductions as to the value, economy and success of the method when studied over a period of years. It is our belief that it would be very unwise for the State to proceed on a large scale with this method of reconstruction. It should be handled with reserve and caution and more in the light of field experimentation than a rigid policy of reconstruction. Two course concrete pavement construction has given indifferent results throughout the United States and has now been completely abandoned in favor of one course construction. In adjacent states on this coast the two course concrete pavements built some years ago, are all more or less afflicted with longitudinal and diagonal cracks and show other signs of grief.

The present State highway method of surfacing distressed concrete areas with a Topeka asphalt surface is, generally speaking, a sound construction policy based on ample precedent throughout the United States. Almost every important municipality in the country has had more or less experience with the asphaltic binder course in conjunction with sheet asphalt and the Topeka or asphaltic concrete wearing surfaces, all laid on rigid concrete bases. That the average experience has been successful can be easily proven by statistics. State Highway experience in California over a period of six years with these surface mixtures—on both new and old concrete bases—has been such as to warrant a continuance of the method. This, however, by no means implies that a plant mixed asphalt wearing surface **can be applied to any kind of fractured or ruptured concrete road already in a state of dissolution and the old road saved thereby.** In many cases it would be more economical to tear up the old concrete road and rebuild the entire section than to attempt its repair piecemeal. The surface must be applied with judgment and discretion or failure of both old and new work is inevitable. The undersigned have seen too many failures of plant mixed asphalt wearing surfaces that could be traced invariably to a weak and faulty concrete base, the latter due principally to inferior or questionable work. Failures—where Topeka surface has been laid on an old concrete road 4-inch in depth and of doubtful value as a base—are not unknown on the State Highway system, and unless extreme care and judgment are used in a policy of surfacing with plant mixtures it is safe to predict a long line of pavement failures with this class of construction in the next few years; failures that will mean tearing up and rebuilding the entire road section with a heavier and more lasting type of pavement, in which event the money expended on the old road for renewal of its life would be wasted.

Black (Asphaltic Concrete) Base vs. Cement Concrete Base 7.7

It is not the intention of the writers to enter into any prolonged discussion as to the merits of "Black Base" over cement concrete base, or vice versa—both are valuable paving aggregates. In the case of "Black Base" California road engineers will be able to judge for themselves in a few years by comparing the life, maintenance costs and condition of "Black Base" roads in various counties of the State under varying conditions of subsoil, drainage, temperature and traffic.

Practically all roads built under the jurisdiction of the California Highway Commission are of rigid base construction, i. e., Portland Cement concrete. Due to this almost universal practice of rigid base construction, our investigation of the State Highway system brings to light only a few examples of the so-called "Black Base" for purposes of comparison as to the respective value of this type when compared with cement concrete.

It is also apparent that the large mileage of cement concrete roads in the State—when compared with the small mileage of "Black Base" roads, coupled with the **greater age** of the concrete roads and unusual conditions of subsoil, traffic and drainage—do not permit of any com-

parisons of great value. Two cases are cited in this article. They cover merely a statement of facts as such appertain to the State Highway system only. No attempt has been made to go into the different counties for comparative data on the subject, this report confining itself to State Highways only.

The examples of "Black Base" construction on the State Highway system already referred to, are as follows:

(a) Dublin Canyon, Alameda County, 2.75 miles.

(b) Santa Barbara County, between La Patera and Carpinteria, 12.25 miles.

Both of these roads were built by and at the expense of the respective counties and were taken over by the State some years ago, thus becoming a part of the State road system.

(a) The Dublin Canyon road is a plant mixed asphaltic concrete approximately four inches in thickness. Its present age is about eight years. Since its acceptance by the State, maintenance costs for the replacement of broken down areas have been heavy. From present indications, the road has already lived out its allotted span and must be maintained by continual patching at heavy cost or entirely replaced.

(b) The 12.25 miles of "Black Base" construction in Santa Barbara County has a very interesting history. This stretch of road was built in 1913 and 1914. It is approximately four inches thick; a two course plant mixture, consisting of asphaltic concrete base and asphaltic wearing surface. The Summerland-Carpinteria section, completed in 1914, showed signs of early failure. Repairs began immediately after the road was turned over to traffic. In its first year of service a considerable portion was re-topped. After less than six years of very inferior service, the road is practically a failure and is now being torn up by the State forces and replaced with concrete.

In comparison with this section of "Black Base" there are found two sections of 1:2½:5 concrete State Highway, one at Serena Gap 0.7 miles in length, and one south of Carpinteria 2.35 miles in length. The first section is in the center, and the last named section at the southerly end of the "Black Base" section. These two sections were built in 1914 and are therefore practically the same age as the "Black Base" road. They are subjected to the same conditions of traffic. Both are in excellent condition today after a lapse of nearly seven years.

The Santa Barbara-La Patera "Black Base" section is of similar construction, although a year older than the Summerland-Carpinteria section described above. The portion between Santa Barbara and Goleta was built on a most ideal sandy loam subgrade and the plant mixture was carefully prepared and placed under expert advice. This portion of the road is still in fair condition after a lapse of 7½ years, but maintenance has now become so heavy and replacements so increasingly frequent that its partial early reconstruction will be necessary from the standpoint of pure economy.

The extreme westerly portion of the road known as the La Patera section began to show signs of failure in 1915. It has been patched and repaired until very little of the original construction remains. Today it is a complete wreck and is to be replaced by the State with concrete.

Immediately contiguous to the Santa Barbara-La Patera section described above is found a 4-inch concrete section of State Highway built in 1915. A comparison of the two types of roads under somewhat similar conditions of subgrade, traffic and age, is most favorable to the concrete base, despite its lean mixture (1:2½:5) and thin section.

In justice to this "Black Base" construction it is but fair to state that the La Patera failure can be attributed in a large measure to poor drainage. The Summerland-Carpinteria failure has been attributed to numerous causes, among which may be mentioned the use of a poor grade of natural bitumen taken from the Carpinteria deposits. This latter statement should, however, be accepted with reserve.

If it is the desire of your association to make comparative studies of the relative value of asphaltic concrete mixtures when used as foundations for pavement surfaces, as already stated, little or no conclusive data can be secured from the present State Highway investigation. The subject is a large one and will require extended examination of county and municipal work in this State as well as investigation and research in other states where this type of construction has been extensively used. Any mere superficial examination of one particular section in California with a view to arriving at definite conclusions would be illogical, must necessarily prove inadequate due to such a restricted and limited field and hence would be inconclusive and of little or no value.

Concrete Aggregates

In general, concrete aggregates used in the State Highways have been good; particularly coarse aggregate. Sand has often been a source of much worry and trouble to the division engineers, and there are many instances where low quality sand has been used, based on comparative tests with Standard Ottawa. Better concrete and consequent better roads would be the result if coarse aggregates were graded as is done in Washington, Oregon, and many other states. Due to the importance of high quality sand in concrete road construction, the supply source should be worked out well in advance of the construction work and, if necessary, one or two State owned and operated sand plants located in each division if high grade sand is not obtainable from commercial plants. The question of obtaining sand is too often left to the division engineer without the authority or means to secure the best possible source of supply.

Low Ultimate Strength of Concrete in California Roads 8.2

California has long been credited with building the leanest concrete roads in the United States. Nearly all of the large mileage of concrete roads built by the California Highway Commission in the interval from 1912 to 1917 was composed of a lean 1:2½:5 mixture. Since 1917 the practice has been to use a richer mixture, somewhat better than 1:2:4, due to excess cement.

In order to compare the low ultimate strength of the California concrete mixtures for the interval between 1912 and 1916—the most active period of highway construction in the State—the following data is taken from the 1918 biennial report of the California Highway Commission:

SUMMARY OF TESTS—28 days—1:2½:5 mixture

Up to 1916	First Crack	Total Break
High Value	2,797	3,000
Low Value	721	766
Average Value	1,680	1,980
During 1916	First Crack	Total Break
High Value	2,234	2,900
Low Value	627	753
Average Value	1,727	2,232

From a report of the State Testing Engineer dated April 10, 1919, covering tests made on 1:2:4 concrete in 1917 and 1918, a decided increase in ultimate strength is shown:

	1917	1918	1917-1918
No. Tests	41	33	74
First Crack	1,856	1,989	1,916
Ultimate Load	2,478	2,610	2,523

The above are average strengths. The low ultimate is given as 1,413; high 2,500+. The report concludes:

> "The testing of field concrete should be given serious consideration. **Certainly the strength of concrete in our construction work cannot be determined from the present laboratory tests.** These tests indicate what the materials can do under carefully controlled conditions, not what they will do under other conditions. Because one attempt to secure field samples was a failure, it does not follow that another one will be."

There can be little or no question as to the value of tests made from samples taken in the field; the contrary is true of samples made up under ideal laboratory conditions.

Considering the low ultimate concrete strengths for the period 1912 to 1916 as shown above, it is logical to assume that this would of itself account for a large percentage of the road failures of the earlier sections on the State Highway system irrespective of the thin four-inch road slab. Even assuming that the road slab was built on a most ideal subgrade, such as hard-pan, decomposed granite or even rock—thus eliminating the more common cause of failure, i. e., flexure—with a low ultimate strength the concrete might easily fail by direct compression. A simple computation will help make this latter point clear. Consider a slab on an unyielding subgrade and a static load due to the rear wheels of a heavy truck; 8-inch tires. The load on the two rear wheels is taken at 20,000 pounds, or 1,250 pounds per square inch. With concrete showing an ultimate strength as low as 650 pounds, the result is obvious. Actual weighing of overloaded beet wagons and trailers on the State Highways in San Benito County resulted in the discovery of loads up to 1,600 pounds per inch width of tire. The 4-inch concrete road over which these loads were being hauled naturally broke down in numerous places. Similar examples in other sections of the State are a matter of record.

As already stated, a concrete of richer mixture is now being used on the State Highways. In consequence, higher ultimate strength must follow, providing care is taken to secure regulation of the water content and the full mixing period. Of equal importance is the grading of the coarse aggregate and, more particularly, the quality and mesh composition of the sand. In other states it is common to find clean sharp sand used constantly in road work with ratios as high as 150 per cent when compared with Standard Ottawa sand. In California it has not been uncommon to use sand testing as low as 70 per cent of the Standard Ottawa in twenty-eight days. Such a sand naturally accounts in part for low strength concrete.

The United States Government has recently completed a series of core tests of concrete taken from selected areas throughout the State Highway system. It is possible that these test cores may show high ultimate strength on many of the older sections, due to the lapse of time since the concrete was first laid. This is not at all unusual.

Compression tests made by the United States Government (Burr E. & R. of M. of E., page 409) gave the following differences in strength in one and six months:

1:2:4 Mixture	Mean of 3 Tests
1 Mo.	6 Mo.
Pounds per square inch.	Pounds per square inch.
3,287	5,669
3,587	4,582
3,233	4,983
2,238	3,506
2,428	3,953
2,420	4,411
2.642	3,643
2,269	3,612

As a general statement the ultimate strength of Portland cement will increase from 40 per cent to 50 per cent after aging one year. (Candlots Ciments et Chaux Hydrauliques, 1898, pages 446/447.)

The crucial test, however, is not the high ultimate strength of a concrete due to age, but the ultimate strength of the concrete when the road is thrown open to traffic, usually twenty-one days after its completion, and sometimes less, according to circumstances. In this "critical period" internal rupture may occur from first load concentrations that eventually will cause disintegration and failure of the road slab.

It is our opinion that the minimum ultimate strength of concrete in compression should be 3,000 pounds per square inch in 28 days and that this ultimate should be determined, not by special laboratory cylinders but from samples secured in the field under actual working conditions.

That 3,000-pound concrete is not an unusual requirement, but rather a prevailing practice, is evidenced by a few examples.

Mr. H. Elting Breed, First Deputy Commissioner, New York State Highway Department, is quoted as follows:

> "We not only test all materials before they go into a pavement, but we test the mixture of the concrete as laid, 6-inch cubes being taken from batches at intervals and sent to our laboratory, where they are tested at the end of twenty-eight days. Our requirement is for 3,000-pound compression test per square inch of surface, etc."
> —News Record, Vol. 74, page 654, paragraph No. 22.

The State Highway Department of Washington requires a high ultimate strength for all concrete, particularly in road slabs. From information furnished by Mr. James Allen, M. Am. Soc. C. E., State Highway Engineer, the ultimate strength in compression—28 day tests, 1:2:3 mixture—varies from 1,800 pounds low to 4,200 pounds high, with an average over 3,000 pounds.

Of twenty-two tests recently made by the City of Seattle the following results were obtained:

Twenty-Eight Day Test

1:2:3½ Mix 3.5 Cubic Feet Cement per Barrel

No. Tests	Max. Lbs. Square Inch	Min. Lbs. Square Inch	Average Lbs. per Square Inch
22	4,605	2,706	3,481

Deterioration of Cement Due to Storage 8.3

It has been the general custom for years past to store large quantities of cement in sheds, barns, and warehouses along the line of State Highway contracts.

Such cement has remained in storage for varying periods, and in some cases more than a year, before being used. In consequence, it has often caked and hardened from pressure and moisture, so that rescreening has been resorted to in order that the cement might be used and much waste due to lumpy cement has occurred, entailing considerable loss.

During the war, due to car shortage, it was necessary to store large quantities of cement or face the alternative of closing down construction work. Storage was therefore probably justified in the face of going contracts and probable loss to contractors.

Recent experiments made by Professor Duff Abrams of the Lewis Institute, Chicago, show cement stored three months in yard sheds lost 20 per cent of the original strength; and after one year the loss was over 39 per cent. (Bulletin No. 6, Structural Materials, Research Laboratory.) The average concrete strength of cement stored in sheds for all periods of storage resulted as follows:

Seven-day test—64 per cent of strength when received from warehouse.
Twenty-eight-day test—71 per cent of strength when received from warehouse.
Six-month test—78 per cent of strength when received from warehouse.
One-year test—82 per cent of strength when received from warehouse.
Two-year test—85 per cent of strength when received from warehouse.

The experiments are interesting and illuminating and throw light on a question often perplexing to the road engineer.

If the storing of cement causes even a **minor loss of strength, there is every reason why the practice should be abandoned or at least resorted to only in cases of extreme emergency, in which event additional cement or a richer mixture should offset the approximate loss due to such storage.**

Dry Concrete vs. Wet Mixtures 8.4

This question has been so thoroughly investigated and discussed in the past few years, particularly in relation to road construction, that it is only necessary to comment upon it very briefly.

It has been conclusively proven that dry concrete is necessary to efficient road construction. Professor Duff A. Abrams of the Lewis Institute, in a very exhaustive analysis, demonstrates that with sloppy concrete in road work "**two-thirds to three-fourths of the possible strength of concrete is lost.**"

To secure the so-called dry concrete, regulating the water content by the slump test, is by no means an easy matter in this State, due to the variable types of mixers in use. The present chute mixers are the most prolific source of wet or sloppy concrete. Very often no two batches will be turned out of the same consistency, the tendency being to increase the water content in order that the concrete will flow down the chute without the assistance of hand shoveling. The boom-and-bucket method and the revolving spout (the latter used with excellent results for a number of years in this State, but now almost abandoned) are practical working mechanical means of securing dry batch mixing without the everlasting friction between engineer and contractor so common on many road jobs.

It is quite natural that a contractor using a chute mixer should aim to turn out concrete that will flow freely down the distributing chute without the aid and extra expense of hand shoveling; also a wet concrete is more easily worked by the concrete crew and labor is more apt to "stay on the job" when such heavy work as striking off and tamping dry concrete is reduced to a minimum. In this connection, however, the consistency of the "dry mix" has a very important bearing. There is a marked difference between a plastic mass of workable concrete with dense mortar content and sufficient water to allow of proper working, and a mass so dry that it requires considerable extra effort in shoveling and tamping to bring forth any excess moisture. The latter is not the mix required or needed. The working of the proper dry mix entails little if any extra effort on the part of the concrete crew. On the other hand, alternate wet and dry mixtures turned out by the ordinary chute mixer (this latter not due to any mechanical defect in the mixer, but to the mixer operator endeavoring to satisfy both the engineer and the contractor) cause all the grief and prejudices the average concrete crew has against dry mixtures in general.

As the dry mixture is so vital to the integrity of a concrete road, future State work should be rigidly safeguarded in this respect; even to the extent, if necessary, of specifying the type of mechanical means that must be furnished by the contractor to accomplish—with the smallest amount of effort and expense—the object to be attained.

The Commission can set a good example by rigidly enforcing the dry mix requirement on all day-labor and general maintenance jobs carried on by the State forces.

Central mixing plants of large capacity, so little used up to the present in California, offer an excellent means of control of moisture consistency of concrete, and more thought should be given to the possible use of this system in planning work.

Present State Highway Specifications 8.5

The general contract and specification under which the State Highway Commission contracts are prosecuted have been subject to little or no important change or revision in the past eight years.

General paving practice is moving ahead with great strides, and no contract or specification that is not subjected to almost yearly amendments, additions and corrections can be classed as modern and up to date.

There are many clauses in the present State Highway contract and specifications that can and should be modified, and the whole brought down to meet the most modern methods and requirements. Vague clauses subject to misinterpretation, general clauses that are not specific, and unusual requirements or hazards that promote higher bids, are all found in the present specification and contract.

Due to the length of this report, it is not possible to take this important subject up at length at this writing. If the Highway Commission accepts the suggestion in the spirit meant and intended, the undersigned will be ready and willing at any time to offer concrete suggestions, amendments and real constructive criticism that may help in modernizing present specifications.

That this is not presumptuous on our part may be gleaned by the statement that the original State Highway specifications were roughed out by ourselves and submitted to the Chief Engineer for approval.

PART III

9. TRAFFIC AND THE MOTOR VEHICLE ACT

We have over 2,478,000 miles of roads in the United States, and of this system less than 300,000 miles can be classed as paved highways.

Of about 8,000,000 motor vehicles in use in the United States, approximately 750,000 are motor trucks.

It is estimated that there is available in the United States in 1920, approximately $175,-000,000 for highway construction.

To expend this money intelligently, it is essential that the highway engineer have a definite knowledge of the character of vehicle and the loads for which he must design pavements.

With the increasing importance of motor vehicle transportation, the intensive development of our manufactures and agricultural assets, and the certain growth and expansion of our system of paved highways to serve these, the burden of costs for constructing and maintaining these lines of communication must be equitably and fairly distributed. In California all of the people assist in paying the interest and funded debt on the sums expended for constructing our State Highways.

The required revenue to meet both interest and sinking fund on State Highway bonds has been derived from

1. County taxes.
2. State revenues (largely the corporation taxes).

The voters at the recent general election approved an act to relieve the counties of the payment of interest on State Highway funds expended in each county, thus putting additional burden on the State revenues. It becomes apparent that, through the corporation taxes, all of the people participate in providing the State Highway funds.

Primarily, as already stated, pavement design cannot be intelligently undertaken unless loading factors are more properly controlled than at present. Hasty legislation influenced by any one coterie of beneficiaries is not providing a solution that will have the least permanence. There are too many agencies vitally concerned to permit of any one of them dictating a policy for the others.

The farmer, manufacturer, jobber and other consistent users of our hard paved highways must be protected in moving his product. The highway official representing the taxpayer must make his investment wisely and with proper safeguards. The motor vehicle manufacturer is entitled to demonstrate the economies of motor truck haulage and the future vehicle best adapted to the demands. Motor transportation companies have legal status and are probably entitled to a voice in highway affairs. It is in a working organization composed of all of these elements together with a special committee from your association that the proper and well advised solution of the highway traffic problem lies.

Such an organization in touch with the national committee of similar personnel, with the data of a complete investigation of the entire problem as applied to California at hand, can not only arrive at proper legislation for the regulation of inter-state and intra-state traffic, but will insure the speedy adoption of such legislation in the State as will be in complete harmony with contemplated Federal enactment.

Legislation in itself, however, is of little value unless backed up by forceful and consistent enforcement. Sufficient data is at hand to show that between 10 per cent and 15 per cent of all motor trucks traveling on California State Highways are overloaded anywhere from 25 to 100

per cent by comparison with manufacturers' ratings. It is conservative to estimate that fully 50 per cent of these overloaded trucks violate the present State vehicle loading law of 800 pounds per inch width of tire. In other words, more than 5 per cent, and probably nearer 10 per cent, of all motor trucks travel the State Highway in open violation of a State law—**and nothing is done about it.**

It is essential that the investment of more then $35,000,000 which we have already made as a State, and the $100,000,000 or more expended by the counties for roads and bridges during the past nine years, be safeguarded against unduly destructive agencies, and it is not conceivable that we will continue to allow a small percentage of highway traffic violators to follow their destructive course unrestricted.

While it is recognized that the present light pavement is not suited to modern day traffic conditions, the extension of the life of such pavements as we have and the conservation of our maintenance moneys can be materially assisted by the elimination of the overloaded vehicle. In this connection we have reference not only to motor vehicles but to the heavily overloaded horse-drawn wagon as well. Records on horse-drawn vehicles show loads running as high as 1,500 and 1,600 pounds per inch width of tire.

Your association is in a particularly favorable position to undertake the leadership in a general examination looking toward the proper solution of this vital problem. The Highway Commission has realized the need for a modification of the law and its enforcement and will undoubtedly co-operate with you as has already been expressed.

In this same connection it is proposed to discuss in some detail the motor vehicle tax before discussing specific recommendations.

Indirectly, all of the people benefit with the completion of hard paved highway systems by the additional distribution and increased facilities for distribution of all of the necessities of living and the development of commercial exchange between communities.

That all of the people should pay for the means of such interchange seems a fair and just distribution.

The direct benefits require closer analysis. We will classify under three segregations the various users of highways, as follows:

1. Pleasure vehicles—touring and sightseeing.
2. Autos and trucks engaged in the business of individual concerns.
3. Passenger cars and trucks engaged in the business of transporting passengers and freight for profit.

The taxing of motor vehicles, primarily for the purpose of maintaining and improving highways, assumes the position that the **user** of the road pay for its upkeep and reconstruction. If all of the people pay for the construction of a system of highways it is only reasonable that the user of that system pay for its upkeep and improvement in proportion to the use he makes of such highways.

It is a fundamental principle that this taxing of the user for the maintenance and improvement of highways should be equitably distributed—and the contention exists as to what is equitable distribution of the tax.

In order to arrive at sound conclusions in levying any tax it is a prerequisite that a definite purpose be assigned, so that estimates may be made in advance of the needs. With a known amount to be levied, we may proceed along the lines of taxing according to benefits received.

The California Highway Commission, by usage, has established certain practices in the expenditure of the moneys received from the motor vehicle tax. It is well known, of course, that of all tax receipts under this law—after the expenses of operating the Motor Vehicle Department are deducted—fifty per cent is distributed amongst the counties of the State and the State Highway Maintenance Fund is credited with the other fifty per cent.

Our discussion here will deal only with the State Highway Maintenance or Motor Vehicle Fund.

Of this annual levy, the California Highway Commission has made use in three distinct classifications, as follows:

1. General State Highway maintenance.
2. State Highway improvement.
3. State Highway reconstruction.

By considering in some detail the expenditures under the above segregations for the past six years we may arrive at a somewhat close approximation of what may be required in future years.

First we will consider the motor vehicle equipment on which the tax must be levied to provide this amount. For the past six years, motor vehicle registration in California has totaled as follows (automobiles and motor trucks only):

	Total Vehicles
Year 1914	123,516
" 1915	163,795
" 1916	212,918
" 1917	306,916
" 1918	364.800
" 1919	477,450
" 1920 (first half)	481,350
" 1920	572,800—estimated total

While the rate of increase is by no means within any constant ratio, a curve based on the mean rate of increase should be accurate for the minimum number of vehicles during the coming ten years. Actual registration may be considerably in excess of the figures derived, but, except in the case of a national panic or other similar disturbance, it should not be less in any one year.

Figure No. 4 following is a graphical exposition of the probable increase in total registration—automobiles and motor trucks, and we find that the total motor vehicle registration will pass the 1,000,000 mark about the year 1926.

Based on automobile and truck registration, the average fee paid per vehicle is approximately $10 per year, and using this figure it is possible to estimate the total fees by multiplying the total number of vehicles in any year by 10.

By deducting approximately eight per cent of total net receipts to provide for the expense of the Motor Vehicle Department, the net total to be disbursed (one-half to the counties and one-half to the State Highway Maintenance Fund) is obtained.

By taking the total maintenance expenditures by years it has been possible to predict with fair accuracy the probable maintenance requirements for future years, and Figure No. 5, following, includes a graphical exposition of this expenditure to 1932. If we add to the maintenance curve, estimated future reconstruction that will be required, the total money that will have to be provided can be found. By plotting the income curve in this same diagram we find that after 1926 the Motor Vehicle Fund will be inadequate to allow proper maintenance and reconstruction. It therefore seems that some change will be required in the motor vehicle tax to produce sufficient funds to meet the needs oi maintaining and providing for the replacement of our system of State Highways.

We are first concerned with the equitable levying of this tax, and it is by means of a more just distribution of the burden of maintenance upon those whose use of the highway is greater, and particularly upon those who capitalize the highways to operate transportation companies at a profit, that this end can be fairly obtained.

It is certainly axiomatic that the greatest user of the highways profits most by a hard substantial pavement.

It is also demonstrable that the greatest wear and tear on paved highways occurs from the operation of fast moving, heavily loaded vehicles—coupled with the cases of illegal overloading of all types of vehicles, both motor and horse-drawn, previously discussed.

These facts established, in fairness to all of the people resident in the State (whose money in the first place pays for the construction of the highways), those agents which obtain the greater direct benefits and those which greatly increase maintenance costs should pay proportionally to use and damage.

The proportioning of this tax for adequate maintenance revenue and the modification of the motor vehicle law is a special study requiring more time than it is possible to devote here. The following tentative suggestions and recommendations are offered for consideration in connection with possible revisions in the present law:

1. The appointment of a special committee by your association to correspond and confer with the National Committee engaged in the preparation of a uniform motor vehicle law. (The national work in conjunction with the Department of Roads is being undertaken by the American Association of State Highway Officials, the National Automobile Chamber of Commerce, the American Automobile Association and the Highways Industries Association.) Your committee to have power to hold joint meetings with State Highway officials, Chamber of Commerce representatives, automobile and motor truck agencies and manufacturers, county officials and motor vehicle owners, and to assist in securing such legislation as jointly may be deemed just and fair and in conformity with national legislation proposed or in prospect.

2. Your committee to consider revision of traffic laws with special reference to permissible speeds and permissible wheel loads, increase in motor vehicle taxes and definite provisions for enforcement of the law.

It is suggested that the following points be considered in conjunction with the motor vehicle tax.

1. Retention of present horse-power tax as a basis of registration.
2. Adoption of a gasoline tax on all gasoline for motor vehicle use to be paid to the Motor Vehicle Department by the oil companies engaged in such sale—one or two cents per gallon. (One cent is equivalent to one-tenth cent per mile on the average vehicle and to one-twentieth cent per ton mile in the operation of a five-ton truck.)
3. The regrading of the tax on commercial passenger vehicles based on a passenger mile charge. Suggested one-tenth cent per passenger mile capacity additional to the horse-power tax.
4. Regrading of tax on motor trucks.
   - (a) Tax on trucks to be graded, imposing heavier rates on trucks in proportion to increase in weight and carrying capacity.
   - (b) On commercial freight-carrying lines—a tax of one-twentieth cent per ton mile additional to all other taxes.

Without considerably detailed study of the question it is not possible to give close approximations of the revenue that may be derived by the adoption of the recommendations noted. That it will be greatly augmented is self-evident, and to an extent sufficient to take care of maintenance and reconstruction needs for a considerable period of years is certain.

It has been shown that a greater maintenance and reconstruction fund will be needed; that equitable distribution of the costs of maintaining these arteries is a first principle of popular government; that action is required to prevent abuse of our highways, and the tentative suggestion is proposed whereby your association may do a great public benefit.

We strongly recommend this subject to your further and careful consideration.

The tabulation following compares California motor vehicle tax with similar enactments in Pennsylvania and Illinois, in which motor vehicle registration is approximately the same as in California, and also includes the recent motor tax law of Maryland.

TABLE XVII

COMPARISON OF MOTOR VEHICLE TAX IN VARIOUS STATES

STATE	DETAILS OF TAX	REMARKS

ILLINOIS

Up to 7 pass. 25 H.P.	25 to 38 H.P.	35 to 50 H.P.	Over 50 H.P.	More than 7 pass. autos & motor truck, gross weight: 5000#	to 12000#	to 15000#	over 15000#	Tractors	Dealers tags	Motor cycles	Electrics	Remarks
$8.00	$12.00	$20.00	$25.00	$12.00	$22.40	$35.00	$60.00	$25.00	$12.00	$4.00	$12.00	Motor vehicle limit = 16,000# per axle or 800# per inch of average width of tire.

PENNSYLVANIA

Per horse-power 40¢. Minimum $10.00

Commercial vehicles: less than 2000# chasis	to 3000#	to 4500#	to 6000#	to 7000#	to 8,000#	to 10,000#	over 10,000#	Trailers: 500 to 750	to 1000#	to 2000#	over 2000#	Motor cycles	Remarks
Horse power basis	$20.00	$25.00	$30.00	$50.00	$75.00	$100.00	$150.00	$2.00	$5.00	$10.00	$15.00	$3.00	Gross weight limit 26,000#

Metal tires double above fees

MARYLAND

Per horse-power 60¢. Minimum $10.00

Vehicles for hire	Solid tired trucks (unladen): 1 ton	2 ton	3 ton	4 ton	5 ton	6 ton	7 ton	Trailers
$1.20 per horse pr.	$20.00	$40.00	$60.00	$100.00	$150.00	$300.00	$500.00	1-ton = $10.00, $20.00 each ton addition.

Limiting load to 650 pounds per inch width of tire.

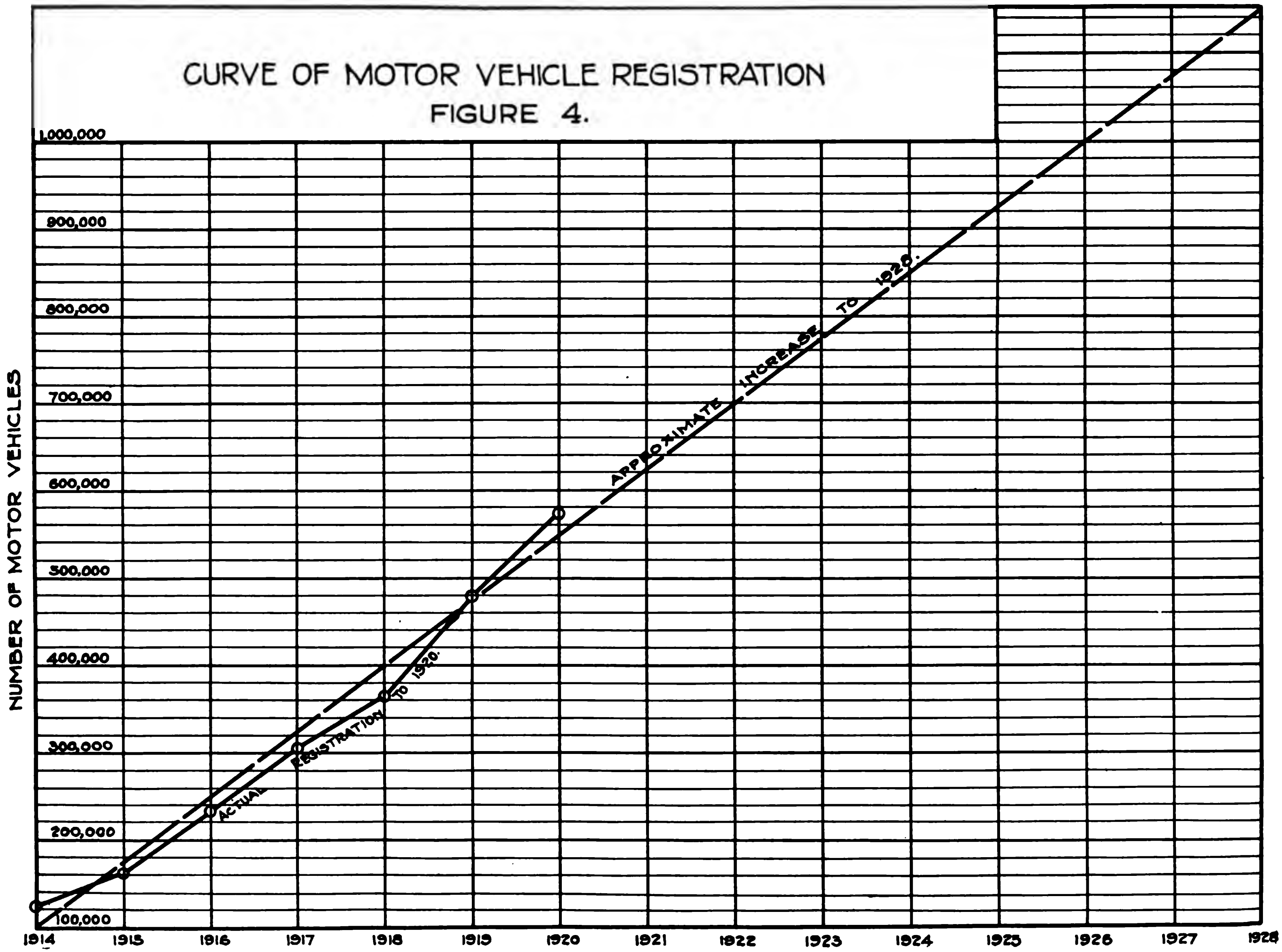
Motor bus on fixed schedule - wt. 3000# - 1/20¢ per seat per mile. 3 to 7000# 1/15¢ over 7000# 1/6¢.

Freight trucks on schedule to 3 ton = 1/5¢ per ton capacity per mile. 3 to 6 tons 2/5¢ over 6 tons 3/5¢

CALIFORNIA

Per horse power 40¢

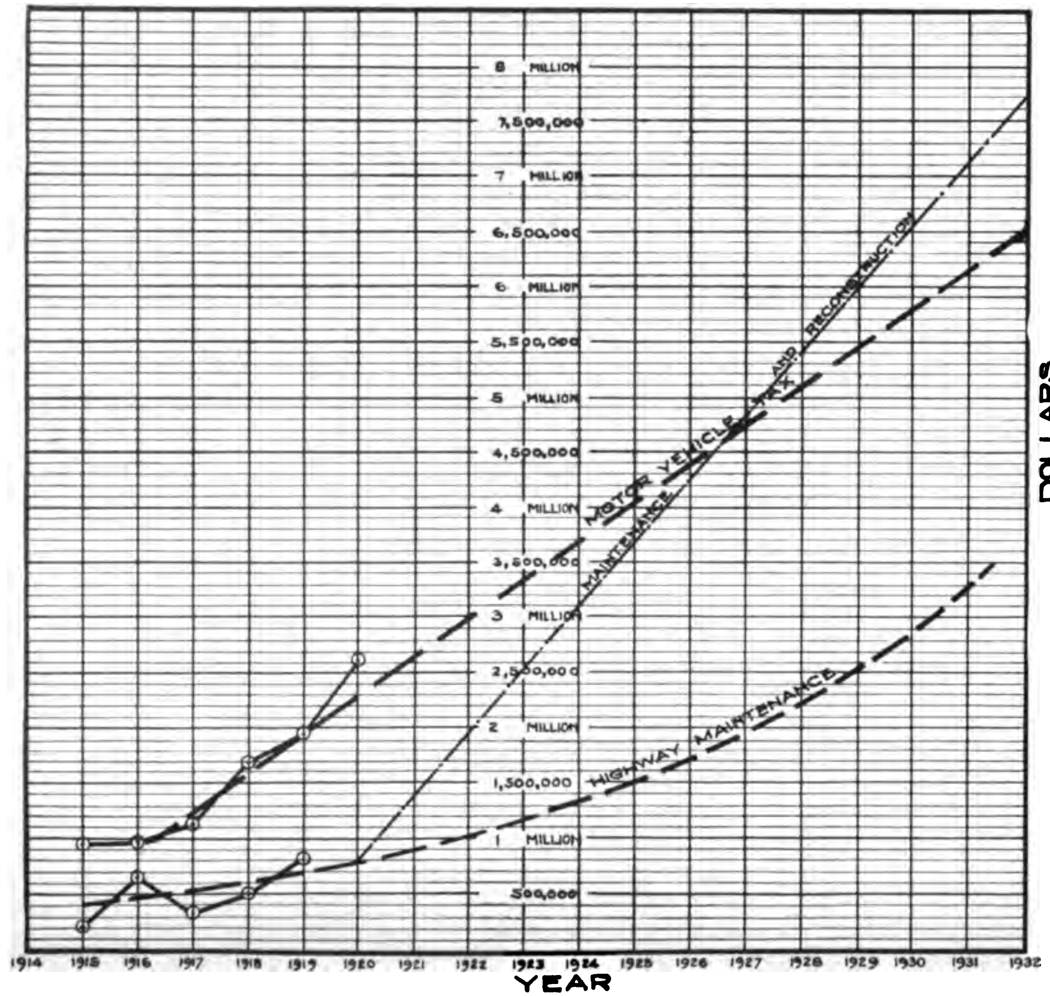
Solid tired trucks (unladen): under 4000	to 6000	to 10,000	over 10,000	Dealers	Electrics	Motor cycles	Remarks
$5.00 plus H.P. fee	$10.00 plus H.P. fee	$15.00 plus H.P. fee	$20.00 plus H.P. fee	1-set plates = $10.00, each add'l set = $5.00	$5.00	$2.00	Limiting load = 30,000# on four wheels not to exceed 800 pounds per inch width of tire.



CURVE OF MOTOR VEHICLE REGISTRATION
FIGURE 4.

FIGURE 5.

CURVES OF MAINTENANCE–MAINTENANCE AND RECONSTRUCTION MOTOR VEHICLE FUND



REMARKS.

Motor Vehicle Tax Curve includes only that portion of net receipts allotted to State Highway.

Highway maintenance curve without estimated reconstruction begins to approach the Motor Vehicle Tax income beyond the year 1930. With reconstruction beginning in 1920 (as it has) added to maintenance, the Motor Vehicle Tax Fund becomes inadequate after 1926.

10. CALIFORNIA HIGHWAY COMMISSION POLICIES

The Acceptance of County Highway Bridges 10.1

On the line of the State Highways in California are found many highway bridges of varying designs and load capacities. Some of these structures are modern, well designed and properly constructed. A large percentage are obsolete and in various stages of decrepitude. The acceptance of the former type by the Highway Commission entails no burden upon the people of the State. The reverse is true of the latter.

For example, the acceptance by the State of the Rincon Causeway in Ventura County, consisting of a series of flimsy pile bents with a wooden deck, is inconsistent with the non-acceptance of the Bradley, San Ardo or Soledad steel and wooden truss bridges in Monterey County. The acceptance of wooden trestles in San Diego and Los Angeles Counties is questionable in the face of the non-acceptance of wooden pile bent structures in San Luis Obispo and numerous other counties. The acceptance of the old Santa Maria River bridge in the face of adverse engineering reports and the non-acceptance of similar structures equally as good or better in other counties, is subject to some explanation. Innumerable additional examples can be cited, but the above are sufficient to illustrate the practice.

Apparently there is no stated policy governing bridge acceptances by the State Highway Commission. So far as we are aware, there is no obligation or law that requires the Commission to accept any of the obsolete county bridges and wooden trestles on the line of the State roads.

By an original agreement with most of the counties of the State, the Commission was to build the State Highway and all necessary drainage structures up to 20 feet span length, while the counties were to furnish the rights-of-way and bridges. The latter referred to new bridges, and only to those designed and built in accordance with the Commission's requirements. Existing bridges on the line of the work that were of modern design and proper construction were logical structures for acceptance and future maintenance. Unfortunately the vast majority of the county bridges were so light, of obsolete design, or so aged and decrepit that very few were considered as logical structures for acceptance and upkeep. This was the unwritten policy of the original Highway Commission. Its soundness and justice to every section will be apparent when it is stated that a county like Santa Barbara bonded itself in the sum of $300,000 in order to build a series of the most modern reinforced concrete bridges on the line of the State Highway. San Benito County, with only a very few miles of State Highway within its boundaries, relegated two decrepit wooden bridges to the scrap heap and built in their place two modern, up-to-date steel truss bridges, costing $54,000.00. San Luis Obispo County spent nearly $100,000.00 for new and modern highway bridges, and in doing so scrapped both pile bent and steel struss structures, while Monterey County expended a very large sum for the same good cause. There are numerous other parallel cases in the State.

It is an act of grave injustice that requires one community to bond itself, or heavily deplete its general fund, to build modern, up-to-date bridges on the line of the State Highway, while another community not only fails to replace its old, decrepit bridges with modern structures, but is actually able to have these selfsame structures taken over by the State; thus saddling both maintenance and reconstruction on the State Highway Fund, probably at the expense of some small community that has been patiently waiting for a section of paved road.

Also in this connection, it is not visionary to predict that **one** heavy wet season in California may easily wipe out old highway bridges on the line of the State roads that would require replacement in the sum of more than $1,000,000.00 That such a forecast is not a remote possibility is evidenced by the destruction of bridges in San Luis Obispo, Santa Barbara and Monterey Counties in the flood of 1914, and the heavy loss of expensive highway bridges and drainage structures on the State Highway in San Diego County due to floods in that section a short time later.

As a matter of common justice to all communities in the State, it is apparent that a rational program of bridge construction and bridge acceptance, so far as the individual counties are concerned, should be worked out by the Highway Commission, and the practice of favoring one county at the expense of another in the matter of acceptances, stopped. The question of what is to be done with all of the old county bridges on the line of the State Highways is becoming more momentous each year. The present dual authority cannot continue without serious future complications. The issue must be faced and the problem satisfactorily worked out on a fair and equitable basis to all concerned.

State Highway Routings 10.2

The California Highway Commission is deserving of great credit for the very logical and almost universal methods adopted in routing the State Highways by way of the most "direct and practicable route." Evidences of sound engineering location are found on every hand. Despite the pressure of local communities and selfish personal interests, the State Highways, generally speaking, have been surveyed and built as main trunk lines should be built, viz.: **By way of the shortest, most practicable and most direct route.**

The Tejon Pass route into Los Angeles, with its saving of more than forty miles when compared with the much vaunted Tehachapi route, is but one of the rulings of the Highway Commission carried to a successful issue in the face of large political pressure. The San Juan Grade vs. the Riverside route into Watsonville; the Zaca Canyon vs. the Alisal Grade in Santa Barbara County; the Sacramento Canyon location and numerous others, stand out as sound, economical and logical routings, conceived by the engineers of the Commission and defended on their merits.

In the face of this splendid almost universal policy, it is indeed unfortunate that any interest or political pressure should have succeeded in swerving the Commission from its avowed purpose to build the main trunk lines by way of the "**most direct** and practicable route."

Attached hereto are maps of the Tulare-Visalia-Hanford route of the State Highway; also the Davis-Vacaville-Fairfield routing. The State roads have been laid out and built as shown on the maps. **They are indirect, longer in distance, and less practicable than the simple direct routes shown in red upon the maps.**

Tulare-Visalia-Hanford Routing

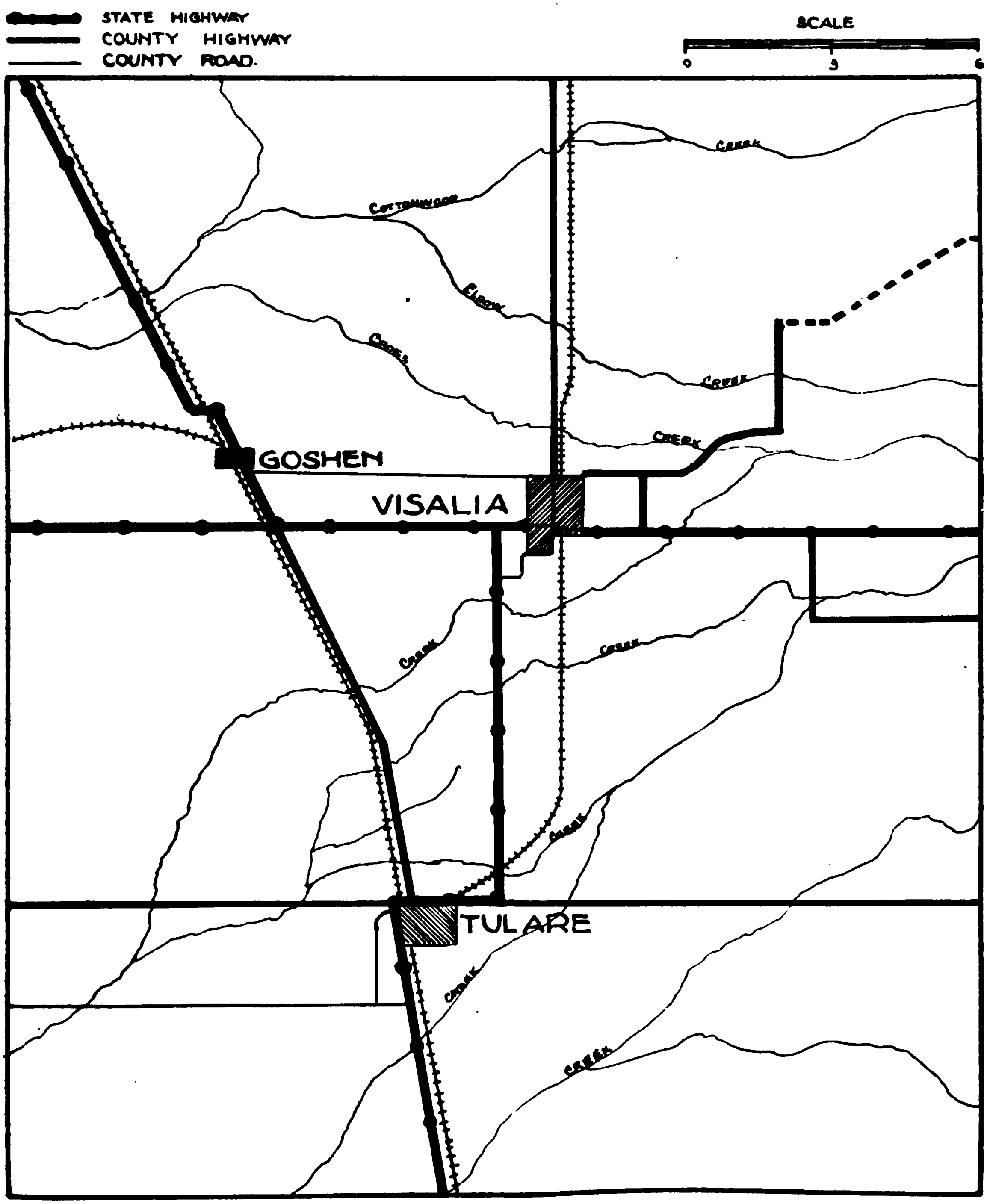
The controversy over the Visalia routing is too well known to require an extended explanation here. That the Highway Engineer and Highway Commissioners practically adopted the direct route is evidenced by the following extract from the Commission's Bulletin of October 15, 1912:

> "After the most deliberate and painstaking investigation of the situation, the Commission and the Highway Engineer agreed that the only practical solution to the situation was to continue the main highway in direct line from Fresno to Kern, passing between Hanford on the west and Visalia on the east, and constructing laterals to connect each with the main highway."

The position of the Highway Engineer and Commissioners was fully sustained in a ruling of the Attorney General, dated August, 1912, from which the following is taken:

> "I am of the opinion that the Department of Engineering may, in the exercise of its discretion, route the main highway, which I may term the Valley Highway, in such a way that it will run either between Hanford and Visalia, connecting them with it by laterals, or through either one of those two county seats, connecting the other therewith by laterals, according to which route that department considers the **most direct and practicable route** north and south through that portion of the State."

MAP SHOWING INDIRECT ROUTING STATE HIGHWAY BETWEEN TULARE AND GOSHEN VIA VISALIA



In closing, the Attorney General wrote:

"Let me say again that in my opinion the main desideratum is a general highway system, **the routes of which shall be most direct and practicable, and that it should be the aim of the Department of Engineering in determining such route or routes of such system, when it shall have determined the most direct and practicable route, to run the highway in such manner that without sacrificing directness and practicability of routes** the county seats of the several counties through which it passes may be connected and the centers of population joined," etc.

There can be no question that the most direct and practicable route lay between Hanford and Visalia, therefore parallel or adjacent to the S. P. R. R. alignment from Goshen to Tulare. and that this direct route was originally selected. Why the Highway Commission receded from its firm and logical position and thrust into the main trunk line a lengthy detour is a ruling that should be fully and freely explained. That there has been a mistake is only too apparent; that the mistake has been somewhat costly is also obvious.

Shortly after the State Highway into Visalia was completed, Tulare County voted bonds for a road system and built the road from Tulare to a point south of Goshen as originally surveyed by the State Highway Commission. Thus, today, the State Highway swings off from a point near Goshen, runs due east to Visalia, thence due south to a point east of Tulare, thence due west into Tulare, increasing the distance on the main trunk line approximately five and one-half miles in distance over what it would have been by way of the "shortest and most practicable route."

The city of Visalia has benefited but little by this change. Through traffic, quite naturally, takes the county road paralleling the Southern Pacific line to Tulare, and so far as the main State Highway is concerned, it merely acts as a side lateral, its principal function being to accommodate local travel to the county seat.

Davis-Vacaville-Fairfield Routing

The Davis-Vacaville-Fairfield road is another roundabout routing increasing the distance between Benicia and Sacramento by approximately 5.4 miles. It is at present of greater importance than the Visalia detour, due to the fact that through traffic from San Francisco, via Benicia, **must** travel the additional mileage without the choice of selecting a paved county road shorter in distance and more direct.

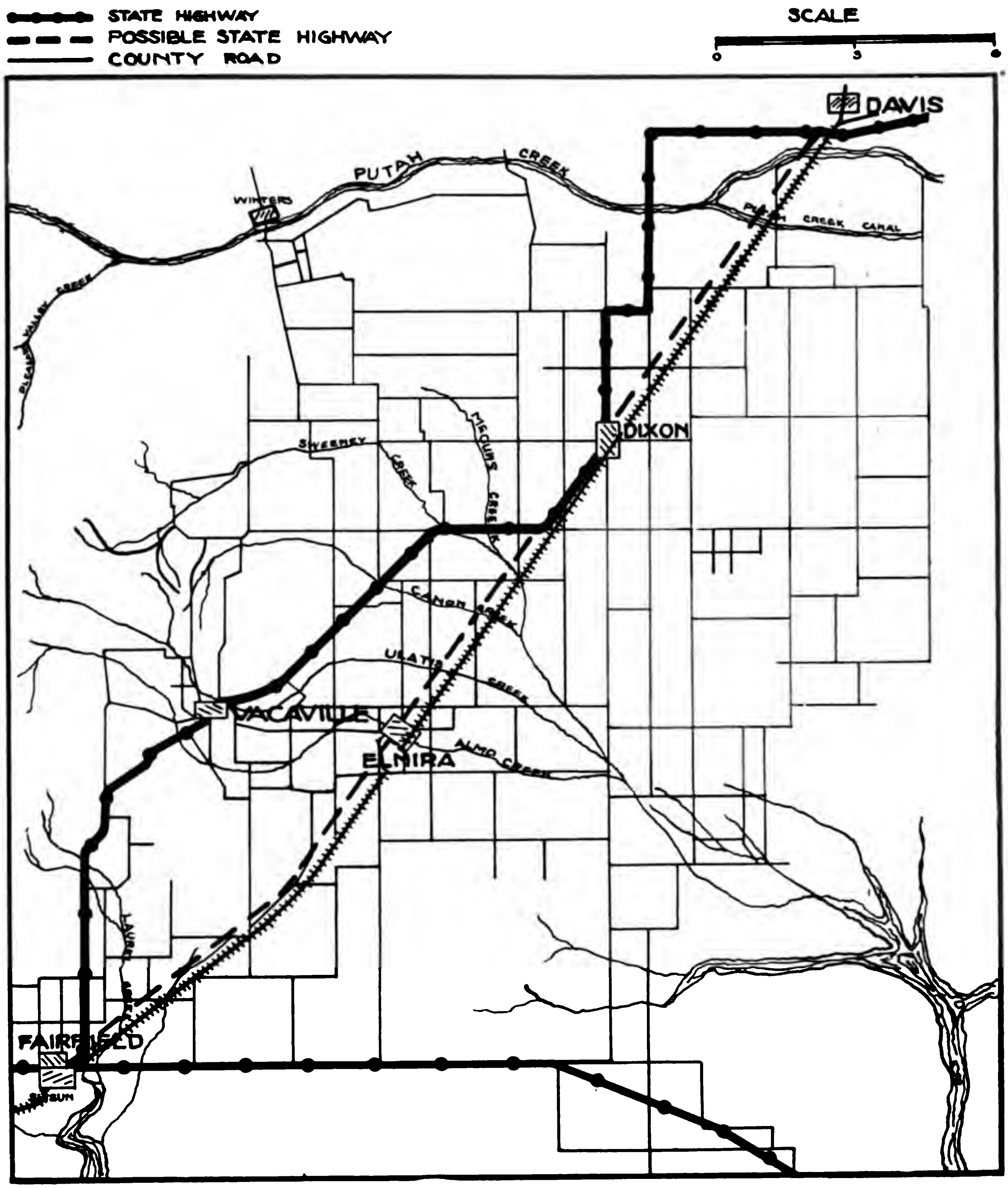
From the Highway Commission Bulletin of October 15, 1912, under the caption "Routing the California State Highway," the following extract is taken, viz.:

"Just as naturally as a great river, like the Mississippi, flows down the trough of the valley, draining into the sea and inviting its tributaries to feed their volume into it; or as a great transcontinental railroad by the economic laws of traffic and engineering is **necessarily constructed by the most direct and practicable routes,** depending upon its tributary lines from both sides to complete its system, so naturally and inevitably it would seem that, in laying out a great State Highway, **directness should be recognized as the first and foremost requirement, in order that it may be serviceable as the main artery of a great highway system.**"

Wonderfully expressed and full of plain truths, but evidently meaningless in its practical application to some State Highway routings.

It is perhaps pertinent to this subject to show in dollars and cents just how much additional cost per annum is added to the traveling public's auto bill by indirect routings such as those enumerated. Taking the Davis-Vacaville route for example: For the purpose of comparison let it be assumed that this road carries an average of five hundred vehicles per day, and of that number two hundred are local residents, the remaining three hundred being through cars or

MAP SHOWING INDIRECT ROUTING OF STATE HIGHWAY BETWEEN FAIRFIELD AND DAVIS



trucks from the bay cities, Sonoma and Napa Valleys, etc. Actual costs based on first cost, depreciation, upkeep, fuel, etc., show an average of from nine cents to twelve cents per mile, depending on the efficiency of the car and the driver. Taking an average cost of say ten cents, we get the following:

300 vehicles per day @ 10 cents	=	\$ 30.00
5.4 miles	=	162.00 per day
Per annum cost	=	58,401.00

Based on a ten-year period, through auto and truck travel over the indirect Vacaville route would needlessly expend the enormous sum of \$584,000.00, or sufficient to build fifty miles of first-class highway at the original price of the Vacaville-Davis road.

Turn Over State Roads to Counties

Of the two routes already discussed, it would appear—**if there are no legal obstacles**—that the State road from Tulare to Visalia would better be turned over to the county, and in its place the direct county road paralleling the Southern Pacific Railroad from a point below Goshen to Tulare, accepted by the State. This road is now acting as a State Highway; it should be included in the system, otherwise if the road falls into a state of disrepair through lack of county funds or poor upkeep, main line travel must again resort to the longer State Highway route via Visalia.

As to the Vacaville Road, there is no apparently insurmountable obstacle to the location of a new road along the west side of Southern Pacific Railroad right-of-way, direct to Davis. In fact, at present there exists an unpaved county road part of the way. This short cut must be built sooner or later. Heavy increase of motor vehicle travel will demand a shorter and more direct route between Fairfield and Sacramento, and good judgment dictates securing the necessary rights-of-way now, and in advance of possible farm and manufacturing plant improvements.

Here again would it not be economy to turn over to Solano County the present State Highway between Davis and Fairfield, building the new route as shown on Map No. 2?

Cholame Lateral

Among the State Highway routes covered by the second bond issue of \$15,000,000.00 is the road known as the "Cholame Lateral." This road was surveyed and located in 1916-17. When completed, it will connect the town of Paso Robles in San Luis Obispo County with Bakersfield in the San Joaquin County, thus producing an outlet from the valley to the coast. This road was located on the most direct and practicable route through San Luis Obispo County. At a point opposite the small town of Shandon, the location follows the north bank of the Cholame Creek, intercepting the present county road at the village of Cholame, some six miles east of Shandon. This part of the routing is entirely new location and was made for pure economic and engineering reasons. The town of Shandon was eliminated from this location due to its geographical position. In order to pass through the town it would have been necessary to throw several right angle turns into the line, cross the Estrella River twice and the Cholame Creek once, and slightly increase the length of line. Proper engineering location demands crossing streams only where necessary either for topographical, industrial or economic reasons. The original location, while unsatisfactory to the residents of Shandon, was not opposed, and the people later became reconciled to the routing due to its close proximity, and committees from the town aided in securing all necessary new rights-of-way for the road. In due course these were signed up and the entire new location tentatively adopted.

Today, more than three years after the original location was decided upon, it is learned on competent authority that it is the purpose of the California Highway Commission to abandon the location just described, cross the Estrella River into Shandon, recross the said river, follow

the south bank of Cholame Creek and cross Cholame Creek at a point near Cholame pumping station, thus not only producing a slightly longer and more irregular alignment but throwing upon the people of the State the burden of upkeep and future replacement of three large bridges, whereas these selfsame bridges are totally eliminated by the original routing.

The County of San Luis Obispo recently voted bonds to construct necessary bridges to connect the State Highway with the town of Shandon. This was the relief desired originally by that community. If the Highway Commission seriously contemplates a change in route to include the town of Shandon and the acceptance of three additional bridges, two of which span a stream notorious for its ravages in abnormal seasons, the reason for such a reversal of policy and the justification for the added bridge maintenance and possible later reconstruction or replacement of these costly structures is not apparent to those who have studied the situation first hand. The responsibility for any change of route lies with the Commission; undoubtedly they are prepared to defend their position.

Other Routings

There are other routings or locations on the State system open to criticism along lines already discussed. It is not the intent or purpose to discuss these minutely at this time. We will therefore merely call attention to the Sacramento-Placerville route, which wends its way into Folsom and then doubles back toward Placerville, and the Oakland-Martinez route to Sacramento, a road so full of grades and excess curvature that its location and actual value to main trunk travel has often been questioned. Today the new Rodeo ferries eliminate the most dangerous portion of the road so far as Sacramento and through traffic are concerned. Thus in a few years a proposed main artery has been relegated to the lateral class.

Routings Under $40,000,000.00 Issue

In the routings to be determined by the Commission under the new $40,000,000.00 bond issue, it is obvious that great care should and must be taken. The people in general are entitled to the most direct and practicable route in the interest of economy and service. The California State Automobile Association can, undoubtedly, assist in securing this result.

The Extension of Aid to Small Municipalities 10.3

The extension of aid to small municipalities in connecting up the main State Highways within their incorporated limits is a question that has been up for considerable discussion in past years, so much so, in fact, that the writers are led to the belief that the matter is worthy of thorough discussion with a view toward the establishment of some definite policy upon the part of the State Highway Commission on all future requests of this nature that may arise.

The State records show that approximately fourteen miles of hard paved roadway has been constructed within the corporate limits of the small cities of California during the past seven years. Originally it was the expressed policy of the Highway Commission to require all incorporated towns and cities to bear the full burden of the expense of paving connecting links to the State Highways, when such construction lay within the limits of the municipality. Various communities that were able to present in a logical way a very strong case, however, both from the financial and desirability standpoints, were able to secure the paving of a portion of the main highway through their towns. Many small communities which requested similar aid, but failed to follow the matter up with any display of strength and aggressiveness, received no assistance from the State, although undoubtedly in many cases they were as much entitled to assistance as those towns in which the same was furnished. The apparent injustice in this makes the matter one worthy of serious consideration.

If it is the desire of the people of the State to assist the smaller and poorer financially, sixth-class cities in paving the State Highway or portions thereof within their corporate limits, a definite and fixed policy should be attempted and the assistance should follow in regular procedure. As referred to previously, it is an established fact that many cities requesting aid were denied, when other cities of like financial condition and area were able to obtain this aid, and it is neither wise nor judicious that a question of the importance which this may have ultimately should not be established upon a definite requirement and a uniform basis.

In the State of Massachusetts there is a law providing that fifteen per cent of the amount appropriated annually for State Highway construction may be used for the purpose of assisting small municipalities to pave connecting links within their boundaries. It is within the power of the California Highway Commission to adopt a similar regulation and to publish the facts, so that all those communities desiring to obtain assistance—and to which assistance will necessarily have to be given if the roadway is to be paved—can, upon proper application, be granted the same privileges as those already extended to some fifteen or sixteen sixth-class cities of California to date.

Dangerous Grade Crossings and Suggestions for Their Elimination 10.4

A trip over the State Highway system is illuminating from the standpoint of railroad grade crossings. It is a well-known fact that the California Highway Commission has grappled with this problem for the past eight years and has done a very wonderful work in eliminating some of the worst death traps in the State. The work, however, has not gone far enough. On the Coast Line of the Southern Pacific Railroad between San Jose and Sargents, in a distance of less than forty miles, there exist today three of the most dangerous grade crossings in the State. Between Salinas and Soledad, in Monterey County, two more are found. The Pizmo crossing in San Luis Obispo County belongs to the death-trap variety, due to the steep approaches and obscured track vision. And so it continues down the coast and up the valley in all parts of the State.

No greater or more humane work could be taken up by the two automobile associations of this State than the problem of grade separations. The following statistics show the number of motorists killed or injured at grade crossings in the United States for the periods given:

Year	Killed	Injured	Total
1917	1083	3010	4093
1918	1131	3109	4240
1919	1232	3558	4790
Total in three years	3446	9677	13,123

The published records of the State Railroad Commission give the following for California for the period between June 30, 1914, and December 31, 1916:

	Killed	Injured	Total
Total in thirty months	229	896	1125

The American Automobile Association has recently started a nation-wide agitation on the question of grade separations. M. O. Eldridge, Director of Roads, A. A. A., is quoted as stating:

> "It would seem that since the elimination of grade crossings is the only sure method of preventing accidents, this work should be continued as rapidly as funds can be secured."

Apparently the theory that legislation causing motorists to stop at grade crossings, also that gates, bells, wig-wag signals and safety-first slogans of the railroads, would prove adequate, is not solving the problem and the elimination of the grade crossing is, as stated, the only sure method.

The California Highway Commission will probably welcome concerted action and aid that

may tend to eliminate grade crossings on a large scale. On account of the engineering features, the interests involved and the Commissions through which this work must perforce pass, it would seem that the logical way to attack the problem would be by the appointment of a strong working committee from the Automobile Associations.

As the separation of grades involves topographical and drainage problems as well as design and construction of subways and overhead crossings, and as many of the problems are purely technical, it is our suggestion that at least one member of the committee be an experienced engineer.

The question of grade separations comes primarily under the jurisdiction of the Railroad Commission. The recommendations of the Highway Commission relative to the safety of the roads under its jurisdiction, however, must naturally have great weight, therefore the two State bodies are more or less correlated on this particular problem. Undoubtedly your committee can secure from both commissions profiles, structure and drainage studies, also cost data covering every grade crossing on the main State Highways, as this subject has been a large one for the past eight years in California. With such information and a summary of the work now laid out together with future plans, your committee will be able to study the entire program carefully and intelligently and thus be in a position to offer concrete aid and advice toward the solution of this big problem.

In passing, we would say the Pennsylvania Railroad is credited with having spent to date some $60,000,000.00 in grade crossing elimination. It will be interesting to know just what amounts have been spent by the railroads in California for the same cause. Action and activity are needed, judging from the number of years that usually elapse from the date of agitation to the actual elimination of the particular grade crossing.

Necessity for Yearly Traffic Records 10.5

Although the California Highway Commission has been constructing the State highways for a period of eight years, during that interval but little concerted effort has apparently been made to secure an adequate and accurate yearly census of the traffic passing over the State roads.

Certain of the Division Engineers have secured traffic counts in their respective divisions and these results are of great value today. For example, Mr. J. B. Woodson, Division Engineer of the Fresno Division, states that since 1913, on the Fresno-Fowler section of the State Highway, the number of vehicles has increased from one thousand per day to four thousand per day, an increase of three hundred per cent in seven years. This is very illuminating data and naturally of great value in road studies. It is unfortunate that similar information is not available for every section of the State (particularly outside the large centers of population) for the period 1912 to 1920, the era of State highway construction.

With a segregated traffic census, including types and weights of motor trucks, widths of tires and overloads, together with counts on caterpillar and wheel tractors, threshing outfits, heavily loaded beet, rice and grain wagons and trailers, not only the volume of continuous traffic with which it is necessary to cope would be determined, but reasonable forecasts of future traffic conditions could be graphically predicted. In addition, the actual increase in wheel loads, due to heavier vehicles and overloads, and the prohibitive concentrations due to variable tire widths on trucks or cleated tractor wheels would be known and this segregated data covering a period of seven to eight years past would now be invaluable for present and future road design in California.

If our information is correct, the Highway Commission now proposes to inaugurate yearly traffic counts in every division in the State. While rather a late date to begin the compilation of such data, in view of the mileage of roads designed and constructed in California to date without such information, it must be conceded that it is never too late to begin research and accumu-

lation of data that will aid in the future rational design and construction of our highways.

It is suggested that the State automobile associations adopt a policy of calling upon the State organization at regular intervals for comprehensive traffic counts and vehicular weights and that this data be kept in the Engineering Department and made available to all county, municipal and consulting engineers in the State.

In this connection we wish to call attention to some extracts from a paper read before the Seventh Canadian Good Roads Congress by Mr. W. A. McLean, Deputy Minister of Highways, Ontario.

"Among the purposes which a traffic census may serve are the following:

1. To determine the traffic importance of one road as compared with another in the same system, and thus to differentiate between different roads as to community value. This data may be useful in laying out a system, especially with a view to granting Government subsidies.
2. To determine the traffic value of the same road before and after improvement. Such information is useful in determining the economic value of highway improvement.
3. To determine the increase of traffic on the same road during a period of say five years, by two different censuses. Such data is useful in anticipating future increase in high way travel.
4. To determine character of traffic, whether farm, local, between centers of population, or tourist, and thus to arrive at a fair distribution of cost.
5. To determine respective percentages of horse-drawn, passenger car, and motor truck traffic, and by comparing previous censuses to estimate future changes with a view to adjusting type of construction.
6. To determine total gross tonnage passing over a fixed point for a period of twelve daylight hours, in conjunction with the speed at which this tonnage travels, useful data in determining: (a) Amount of wear, including impact and displacement resistance sustained by a certain type of roadway, comparing this with maintenance charge per year; (b) whether such roadway is economically fitted to bear this gross tonnage.
7. To determine the importance of various phases of traffic and therefrom determine the loadings and speeds which should be permitted; viz., for purposes of traffic regulation."

Experimental Research and Laboratory Work 10.6

While it is known that the State Highway Commission maintains a moderately equipped testing laboratory located in the State Fair Grounds at Sacramento and that this laboratory is in charge of one of the most experienced, efficient and capable young testing engineers in California, the scope of experimental work, both in the laboratory and field, has been curtailed and limited. A large amount of time and labor has been consumed in endless tests of cubes, cylinders, briquettes, etc., which, while of value in controlling structural integrity of work under way, is easily overdone and sometimes becomes mere repetition and routine.

In order to reduce to a minimum the losses in pavement construction directly traceable to preventable causes, a sum of money should be set aside each year by the Highway Commission to be used for field experiments, research and laboratory work on a broad and comprehensive scale and a proper staff of assistants should be provided to accomplish the purpose intended and desired.

Experiments on adobe soils to determine the ratio of horizontal and vertical capillarity in twenty-four hour periods, would be of untold value in the study of heavy subsoil saturation. In addition, the action of gravity water with reference to adobe and clay soils; their absorption qualities; the percentage and amount of expansion with varying moisture content; the shrinkage or reduction in volume when dry; the properties of these same soils when treated with lime or

special chemical applications and the probable life of such treatment before necessary renewal; the adulteration of the adobe soils by incorporating within the body, sand, crushed rock, gravel, shale or other material and laboratory tests to determine the properties of the soil after such treatment; also numerous other experiments along similar lines should be undertaken by the State Highway Commission and the results given to counties, municipalities and the engineering profession at large.

Beam and slab tests, plain and reinforced, and actual field slab tests on adobe, clay and similar soils—the latter re-worked, adulterated, or treated to break up capillarity; the application of mechanical means to cut off gravity water by the use of rock and tile drains, Telford base stone, macadam sub-base, V-shaped rock under-drains, cut-off walls, sealed shoulders, and treated fill slopes adjacent to drainage ditches, are all practical and logical experiments that offer a large field for study in connection with highway design in an effort to safeguard future construction and reduce pavement failures to a minimum; and in this connection, the following are very pertinent, viz.:

The study of impact with relation to smooth or corrugated pavement surfaces; to flexible asphalt mixtures, construction or expansion joints, buckling, etc.

Beam and cantilever action of concrete slabs of different depths (plain and reinforced) with reference to subgrade settlements and concentrated wheel loads.

Triangular breaks in concrete slabs at expansion joints or contraction cracks and the remedy.

Possible slab failures on ideal subgrades due to direct compression using lean and rich mixtures of known ultimate strength.

The efficiency of lined or paved drainage ditches over cut sections.

The loss in ultimate strength of concrete specimens taken from test sections laid on dry and slightly moist subgrades, vs. carefully prepared subgrades where the moisture has penetrated from above meeting that from below.

Experiments in the field to counteract the effects of alkali on concrete; to overcome surface crazing; to determine the percentage of abrasion on unsurfaced concrete, etc., etc.

The foregoing, while apparently voluminous, covers but a portion of the field of experimentation and research in connection with modern highway construction. Money expended on determinations of this character can be likened to life, fire or marine insurance; it is a safeguard universally recognized and adopted. If provision has not been made by the Highway Commission to date, looking toward an aggressive and far reaching program of experimentation and research in advance of the proposed expenditure of $40,000,000.00 for State roads, it is a grave error and open to the same objections already voiced in this report, with reference to previous construction methods and expenditures.

Comparison of Day Labor Versus Contract Work 10.7

Of a total expenditure of approximately $31,000,000.00 for construction work on State highways, $6,909,000.00 has been spent for day labor work under the direction of the Highway Commission. This policy is therefore such a general one as to warrant a close examination prior to the expenditure of the considerable fund now made available for highway work.

The influence of State highway policies throughout the State is also of importance in that many communities adopt State practice without question, assuming it to be the results of careful investigation and conclusive experience. It is natural for the smaller governmental unit to look to the superior for guidance and, in the question of State highway day labor work, the lesser community is apt to form a conclusion based simply on the great amount of this work performed by the State and the continuance of such operations without any direct knowledge of the facts.

It is interesting to note that the Highway Commission itself can have but a limited knowledge of the detailed costs of day labor work by comparison with contract work although much of such work has been done following the rejection of contractors' bids for the same.

Of the 300 odd day labor operations conducted by the State, segregated costs covering units of work as shown in preliminary estimates were obtainable on but five contracts although total costs on each of the 300 were secured. Total costs are unsatisfactory for comparison as they do not show the amounts of the units of work accomplished and, as final quantities of work often vary considerably from estimated amounts—usually with an increase of the former over the latter—total costs are often misleading.

Of the five segregated day labor costs obtained on State highway work, contractors' bids on two are available for comparison. As these two are of considerably more magnitude than the other three, the comparison gains some importance.

The first of these, Contract 150, completed in Los Angeles County west of Acton in 1918 and designated as Route No. 23, Section D, shows a considerable increase in cost over contractor's bid.

Exclusive of materials furnished by the State (and so specified in the call for bids) the following comparison is arrived at:

Preliminary estimate contract items	$102,532.00
Contractor's bid contract items	117,491.00
Cost by day labor contract items	160,000.00

The second operation available for comparison—a stretch of highway in Contra Costa County, Contract D-153, completed in 1919—affords a still better comparison:

Preliminary estimate contract items	$ 43,142.00
Contractor's bid contract items	64,230.00
Cost by day labor contract items	81,349.00

The two principal items of the work may also be compared:

	Estimate	Bid	Cost
Excavation (pr. cu. yd.)	$0.55	$1.10	$ 1.17
Concrete in pavement (pr. cu. yd.)	4.50	7.50	10.38

As to whether or not these two examples are representative of all the day labor work by comparison with contract work, there is no means of determining at present. There is also some question as to the accuracy of the cost data in that the Highway Commission has not adopted a method for entering proper charges against work to cover shop repairs, interest and depreciation on equipment and this item appears in costs only when equipment is rented or in the early work when some tool or machine was purchased during operations and charged in total to that work. Comparisons may therefore be even more unfavorable to day labor work than the instances given.

While comparisons between day labor and contract work given above may be thought to be too limited to form a basis for definite conclusions, another comparison may be made which will substantiate the statement that, economically, day labor work is not a success.

On twenty day labor operations completed to June 30, 1920, covering concrete base construction of one or more miles in length, total costs are found to be $2,461,725.00; estimates for the work totaled only $1,911,379.00. The excess of final cost over estimated cost is $550,346.00 or 28¾% and on many of the costs making up the total, practically no charge for equipment is entered.

It is probable that some of the asphalt and thin bituminous surfacing work has been installed at costs comparing favorably with contract work, but this cannot be determined unless all plant charges are found and properly distributed against the cost of such operations.

It is a matter of record that the State organization was compelled to take over and complete a large number of contracts through failure of the contractor. If there is a single instance in which the work was prosecuted by day-labor organizations at a final cost below or even approaching the State's original estimate or the contractor's bid, it has not come to light.

Very few engineers believe in doing work by day labor when it is possible to prosecute the same work by contract. The exception may be stated when contractors' bids are exorbitant or where a possible combine exists to the detriment of legitimate competitive bids. In such a case the Engineer is justified in prosecuting the work with his own forces. That combinations of the above character in California have been practically negligible so far as State highway work is concerned, is well known.

In the interest of future economies, and to avoid the mistake of continuing day labor work at possible future loss to the Commonwealth, also for the benefit of counties and municipalities proposing to do work on a day labor basis, it is our opinion that the Highway Commission should cause an immediate examination of all day labor work completed since 1913 with a proper and comprehensive segregation of cost data made up and filed, together with a comparison of the original bids of various contractors. This information should be made available as soon as practicable, in order that the full facts may be known in advance of the proposed highway construction now contemplated on a large scale by the State and the immense expenditures for similar work proposed next year by counties and small municipalities.

Convict Labor 10.8

Under the law enacted by the Legislature in 1915, providing for the employment of convicts on State highway work, several sections of graded highway with culverts and bridges have been constructed by the Highway Commission amounting in all to something less than 100 miles of roadway.

Most of the work was done in isolated mountain districts in Mendocino, Humboldt, Sierra, Calaveras and El Dorado Counties, camps being established close to the work to house the men. The prison authorities administered all disciplinary functions and the Highway Commission directed the actual work and, while divided authority is undesirable and usually leads to waste and inefficiency, it is apparent that this work was well handled.

The outstanding feature of the work lies in the fact that where honor camps were established—that is, where the guards were unarmed—the work progressed more favorably than the same class of work under armed guards and the behavior of the men in camp and on the work compared favorably with free labor. It is apparent that the greatest value of the system is found not in the efficiency or amount of work performed but in the possible rehabilitation of the offender into a useful citizen; the psychology of the honor camps demonstrating the possibilities.

From the standpoint of cost of work, such data as has been obtained shows very good results. A complete and comprehensive report on this employment, both from the effect on the convict and the cost of work standpoints, would be an interesting chapter in the next biennial report of the California Highway Commission.

Cost of Work Affected by Attitude Toward Contractors 10.9

Many notable failures of contractors have occurred on highway work not only in California but throughout the country generally and are largely due to the inexperience of both contractor and officials in charge of work in the early years of extensive programs in hard paved roads.

With the accumulation of experience there has been a tendency of contractors to regard highway work as too highly speculative to be attractive and the official in charge has begun

to "take stock" in an effort to reduce the hazards and make his requirements definitely known in specifications.

During the past two years this tendency of the legitimate contractor to draw away from highway work has become so marked in certain sections that the highway officials in those sections have invited joint meetings with the contractors in an effort to arrive at mutually satisfactory working conditions under which ambitious road building programs could be successfully prosecuted at reasonable costs. Such an instance occurred in Illinois last spring and is reported as productive of excellent results.

It is well known that California contractors have found little profit in highway work in the past. Not only have their losses been considerable, but the list of contracting firms that have become bankrupt on this work is startling. Many of these are no doubt due to a total lack of experience and bids tendered at prices impossible of approximating in execution, found among new firms entering the field with too limited a capital. A certain percentage of such failure is expected and unavoidable under present conditions surrounding the award of contracts on public work. Other failures and losses are not so easy of exact determination. It is certain, however, that highway work in California is proving less and less attractive if we are to credit the statements of the sound and reputable contracting firms who have performed much of this work in the past. Their criticism is so uniformly the same that it seems to us to be worthy of serious consideration, particularly at a time when the most ambitious highway program yet undertaken in California is in the making. In view of this condition, the attitude of the Highway Commission toward all matters affecting highway contractors and the constant recurrence of drastic rulings involving considerable losses, are questions of great weight and moment. Lack of co-operation and a disposition to place all of the hazards of the work upon the contractor is the most common source of complaint. The numerous examples of this rigid policy are too lengthy in description to include here. That they are frequent is borne out by the complaints emanating from reputable sources, and this in itself is food for reflection.

The important concern is the effect of this policy on bids for work. It is well recognized and partly substantiated in paragraph 10.7 that day labor work is not economical by comparison with contract work, and it is therefore to the highway contractors of the State that the Highway Commission must look if they expect to make proper progress in the prosecution of the State highway program.

It is not to be expected that a contractor will operate his business at a loss and it is a certainty that the contemplation of possible losses through some drastic decision on the work has its effect on the prices tendered for that work. Other than recourse to expensive legal procedure, the contractor has no appeal from a Commission ruling and where in the past his experience points to only one result from this body, his protection—if he cares to continue highway work—must lie in his bid for the work.

Many contractors have taken the easier course of abandoning State highway work and altogether the situation must be viewed as unsatisfactory in its present status.

This policy must be considered as shortsighted. Not only is it productive of higher costs for work but in the last analysis the savings effected by penalizing contractors react by greater costs in the final accounting.

11. GENERAL NOTES AND CONCLUSIONS

Distinctive Road Signs or Markers 11.1

The present method of marking main trunk highways, laterals, incorporated town and city limits, etc., is subject to some criticism. The system can be greatly improved upon at low cost.

It is our belief that the present single color road markers should be changed so as to distinguish the State highways from the county road systems; also from the paved roads lying within the corporate limits of municipalities. The reason for special distinguishing markers, we believe, is obvious and needs no discussion.

It is suggested that a distinctive color background such as dark green, black or maroon with white lettering be adopted and a circular or rectangular shaped marker of reasonable dimensions—somewhat along the lines of the designs shown on sketch sheet attached—be considered. If an entirely new shape of distinguishing road marker is used on State highways, the present diamond-shaped marker could be adopted for the county systems.

It is noticeable on the State Highway System that signs of various types and kinds mark many of the county boundary lines. There is a great lack of uniformity and the irregularity is quite apparent to even a casual observer. In some instances there are no signs marking the division lines between the counties.

In addition to the above, obsolete and irregular speed limit signs now grace the outskirts of many municipalities. These signs are not only an eyesore but confusing and contradictory. Uniform speed limit signs strictly in conformity with the Motor Vehicle Act should be erected over the entire State and county highway system. If placed in the hands of one organization, the work will be well and efficiently prosecuted and completed.

Owing to the cost involved in the ambitious scheme of road marking proposed herein, we feel the California State Automobile Association should present this case to the California Highway Commission with estimates of cost and scope of proposed work, asking the State organization to bear the initial expense involved; replacements and maintenance of said signs to be taken care of by the California State Automobile Association, with State aid.

A new departure by the California Highway Commission in the way of section markers has just been made. It is proposed to mark each section of State Highway with the identifying section, route and division. The marker consists of a 6 x 6 redwood post extending two (2) feet above the surface of the ground and located along the right-of-way line of the highway. It will be placed at the beginning and end of each section. While this type of marker is of great value to the engineer it, of course, is separate and distinct from the regular auto sign and in no wise conflicts.

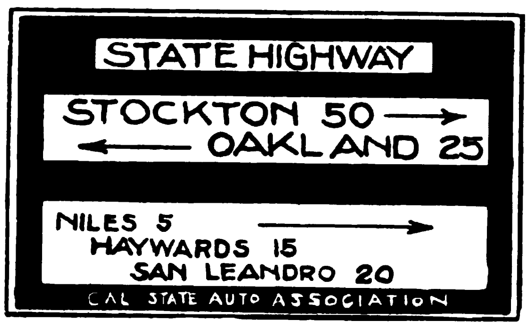
An excellent addition to the marker just described would be to stamp into each concrete section at the end of each day's run, the section, division number, name of contractor and date. This is being done in other states and the information is very valuable in pavement studies.

Inadequate Guard Rails 11.2

The present light wooden guard rail construction on the State Highway System is a source of considerable expense for upkeep, due to continual breakages. The light redwood posts are sheared off and the rail wrecked by very moderate impact. A heavier and more substantial rail would not only prove economical but a greater safeguard for traffic. This is particularly true on the mountain grade sections at points where concrete curb guards are not installed. The present tendency is to install guard rail along low fill sections; on long safe tangents and at other points where its value as a protective measure is questionable.

SUGGESTED TYPES OF SIGNS FOR STATE HIGHWAYS

All diamond shaped Auto Assn., signs to be used on County Road systems



MAIN STATE HIGHWAY SIGN.

INTERMEDIATE ROAD MARKER

TOWN SIGN

INTERSECTING ROAD SIGN

Less and more substantial guard rail installed only at real danger points will give better service and prove more economical.

In this connection, attention is directed to the simple and substantial guard rail used on the state highway in Oregon. It consists of 8 x 8 posts S.4.S.—and 8 ft. on centers. Posts extend 4 feet 3 inches above, and are set not less than 3 feet 9 inches below, the ground level. The top rail is discarded, only two 3 x 8 rails being used. This type of rail has been adopted by the U. S. Department of Public Roads for many Western Federal aid projects.

Grade and Curvature Reductions 11.3

This is a large subject. To cover it thoroughly and exhaustively would require a review of all lay-out plans now completed and an inspection of subsequent field notes covering surveys on road locations to date, together with a field inspection of graded mountain roads and laterals. Such an extensive study is not contemplated by this report. In order to bring this matter to the attention of your association, however, a few specific cases will be cited and general views outlined for future consideration.

So rapid has been the increase of motor vehicle traffic on the State Highways in the past few years, that mountain grade locations made five or six years ago, which were considered at that time as typical of modern methods of highway engineering, are already beginning to show the necessity for some rehabilitation, particularly in the matter of curvature reduction.

On the Coast Route between San Francisco and Los Angeles, this applies in a minor way to the San Juan grade near the summit of the Gabilan Pass, also to the San Luis Obispo side of the Cuesta grade in the Santa Lucia range. In Marin County the Corte Madera grade is particularly in need of curvature reduction.

In the case of the San Juan grade, the widening out of some of the most objectionable curves by throwing the road-bed further into the mountain and daylighting an occasional through-cut will add greatly to the safety of the road.

The Cuesta grade requires even more heroic treatment, due to the series of simple and reverse curves near the summit of the Cuesta Pass and the restricted width of roadway on many of these curves.

Objection might be raised to the reduction of curvature at the expense of gradients. However, as both roads are located on six to six and a half per cent maximum grades (principally the former) slightly increased gradients due to reduced distances, or even the entire absence of compensation on these curves, would be of far less importance than the retention of the curves in their present condition.

The Corte Madera grade in Marin County is becoming extremely dangerous at times, particularly during congested week-end and holiday travel, and extreme care is necessary in order to navigate its tortuous windings without accident.

The present policy adopted by the Highway Commission in paving to a greater width the Conejo grade in Ventura County and installing concrete curbs as wheel guards at danger points, would be very logical improvement for the three mountain grades mentioned above. Wider sections on the mountain grades on main trunk lines or those adjacent to large population centers are naturally more important than on the long tangents in flat or rolling country.

There are many other sections of mountain road on the State system that must sooner or later be corrected in the matter of curvature. Those referred to above are merely typical cases to which early consideration should be given. Much of the improvement can be handled by maintenance crews if it is considered that this work is properly chargeable to the maintenance fund.

A special case of needed grade reduction is found on that section of the State highway known as the Dublin Canyon route between Haywards and Livermore. Several grades slightly

in excess of eight per cent are found on this route. As such grades would be considered as prohibitive on a new location embracing a road so heavily traveled as the Dublin Canyon route, it would seem that an early effort to reduce the grades on this particular stretch of road to a maximum of six per cent, even at the expense of new location, is justifiable and necessary.

In the light of past experience it is very possible that the Highway Commission will find it necessary to carefully review and possibly modify the grades and curvature on the original location surveys for the lateral roads proposed under the second bond issue of $15,000,000.00. A number of years have elapsed since the original field locations were made and it is therefore possible that experience—particularly with regard to mountain grades on the main trunk lines—has already dictated the necessity for lower maximum gradients, increased curve radii, and less total curvature than was deemed apparent some years ago.

Additional Outlet Roads Near San Francisco **11.4**

An official count of traffic down the Peninsula from San Francisco to Burlingame, made November, 1920, between the hours of 6:00 a. m. and 8:00 p. m., resulted in the astonishing total of 19,591 vehicles. This included motor trucks, automobiles, motor buses and teams.

A similar count on the same date, on the Alameda side of the Bay between Hayward and Niles, resulted in 3,126 vehicles.

Between Irvington and Warm Springs—2,108 vehicles, and between Hayward and Oakland (E—14 St. only)—5,487 vehicles.

Despite the lower traffic count, Alameda County roads (on Sundays and holidays) are quite congested. As is well known, there are two main routes through this county, both paved; viz:

Via Foothill Boulevard to Hayward, Niles, Mission San Jose, Warm Springs.

Via E. 14th St. to San Lorenzo, Mt. Eden, Irvington, Warm Springs.

The San Francisco Peninsula is less fortunate. Only one main paved outlet is found below San Bruno.

Recently a movement has been started in San Jose for a relief route in the southern end of the Peninsula.

The proposed Skyline Boulevard along the rim of the hills from San Francisco to Santa Cruz is another contemplated outlet to be built by the State.

In any event, a second independent route down the Peninsula from San Francisco is becoming more and more urgently needed. With such a tremendous volume of travel as that disclosed by recent traffic counts, early action toward relief is imperative if progress is to keep ahead of congestion.

It has been frequently stated that the proposed Skyline Boulevard, a purely scenic road, will relieve the congestion of traffic down the Peninsula. To those who are familiar with the needs and rapid progress of business and commercial traffic, it is apparent that such a route will merely assist. Its primary function will be to afford a diversified route for pleasure vehicles.

It is suggested that this matter be given consideration by your association with a view to a comprehensive study of the Peninsula road problem and its solution.

An additional outlet into the San Joaquin Valley from Oakland is becoming a greater necessity each year. The present route via Hayward, Dublin Canyon and Altamont Pass requires quite a detour to the south for vehicles en route to Stockton and way points. The tunnel road from Oakland and the paved road system of Contra Costa County offer the best possibilities of a more direct and shorter route to Stockton points and should be investigated with reference to possible State or County Highway connecting links.

Immediate Road Needs 11.5

Under paragraph 11.6 following, a program of road construction covering the entire State is discussed. The present gaps in the main trunk lines are therein recommended for completion in advance of other roads.

In central California there are certain sections of highway on the main trunk system that require immediate widening, rehabilitation or reconstruction. They are found on Route No. 4 between Sacramento and Modesto; Route No. 5 between Stockton and Hayward, Route No. 2 between San Jose and Sargent.

The most imperative need for rehabilitation of the old, wavy, corrugated oil macadam roads on these two routes is found in San Joaquin County between Stockton and Ripon and between Manteca and the Altamont Pass in Alameda County. On many of the old county road sections taken over by the State, the condition of the oil macadam due to deep and prolonged corrugations and waves—particularly at the sides—has become such as to restrict traffic to a narrow center strip of road. To turn out upon the deeply furrowed shoulders at any reasonable speed invites disaster.

On Section B, San Joaquin County, north of Tracy on the main road to Stockton, is found a long, narrow, poorly paved fill without guard rails. The height of the fill, the narrow width and the congested traffic at times, stamp this stretch of road as a dangerous menace to auto traffic. There is apparently little need for such a high fill section, judging from the adjacent farm country. To cut down and widen out this fill and adequately protect it with substantial guard rails, is a simple job for a good maintenance crew.

In Sacramento County, between Galt and Sacramento, scarifying and re-rolling have improved the old oiled road, but the work is not of a permanent character as evidenced by the poor condition of portions of the newly rehabilitated road sections after a few months of travel.

The greatest economy of effort and money would be served by tearing up these old oil macadam roads and rebuilding with standard construction, using the old rock for shoulders or adobe base adulteration.

In Alameda County, between Livermore and the San Joaquin County line—particularly in the Altamont Pass—early action is imperative in the matter of reconstructing and widening the present fifteen-foot road to at least twenty feet. The traffic through this Pass has increased so rapidly that accidents are becoming more common each day and unless something is done to relieve the present condition, the toll from accidents will be heavy.

In this connection, it is difficult to understand a policy that proceeds to build new 18-foot concrete roads in the sparsely settled districts of Butte County and the uninhabited mountain sections of San Diego County while so vitally important and heavily traveled roads as the Altamont Pass into the San Joaquin Valley are allowed to remain so narrow and dangerous a width as fifteen feet.

Other important sections in need of early attention are the widening of the fifteen-foot roads in Santa Clara County between Coyote and Sargent; similarly in the congested districts near Fresno and on the Modesto-Salida section in Stanislaus County.

It is our suggestion that your association present a formulated program along these lines to the Highway Commission for their consideration.

A Possible Program to Cover Expenditure of Remaining Highway Funds 11.6

That this subject is particularly difficult of solution is only too apparent. Probably no absolute program covering any considerable period of years can be laid down now and followed exactly as the work progresses.

Many factors enter into the difficulty of establishing any kind of a program or in making any very definite estimates of cost that may be found accurate two or three years from

date. It is our belief that with the general improvement of labor conditions throughout the country and the tendency toward lower price levels in many of the materials of construction contract prices and construction costs will be materially lowered within the next year period, so that any estimate, based on present day prices and knowledge, may show only a possible curtailed program which in a short period can be considerably increased and expanded, due to lower price levels. Therefore, it must be clearly understood that our conclusion as to roads that can and should be built within the expenditure of the present available highway funds, is based entirely on present day prices rather than upon any estimate of cost one, two or three years hence.

There is an additional factor which may expand the program submitted herein. It is the possibility of an additional Act by Congress covering Federal road aid appropriations. There are two bills which may come before the next Congress, one of which is called the Townsend Bill and the other the Chamberlain Bill, and it is very probable that one of these proposals will be adopted before the end of the Congressional session. Under either bill, over $400,000,000.00 is called for in the extension of Federal aid to the various states and if the apportioning of this amount follows along the same lines as that in the original Federal aid already established, California's share would approximate sixteen to eighteen million dollars or about one-half of the total money available in the State at this time for highway construction.

With this grand total of some $57,000,000.00 augmented by additional surplus from the motor vehicle tax, it is apparent that a considerable mileage of highway would be possible of construction.

For the purpose of arriving at some definite figures we have more or less arbitrarily divided the remaining roads under the various bond acts into three classifications, as follows:

(1) Primary roads.
(2) Secondary roads.
(3) Roads providing limited service.

Briefly we may define these as follows:

(1) Primary roads are those uncompleted sections on the main trunk highway system connecting larger centers of population, important county seats or furnishing direct connections for inter-state travel.
(2) Secondary roads are those highways not yet completed which reach out from the main trunk system to connect with minor centers of population and smaller county seats.

Both primary and secondary roads are considered of sufficient commercial value as to return—in a saving on haulage costs—more than sufficient to pay the interest and refunding on the cost of construction.

(3) Roads providing little service are those highways included in the Act of 1919, which are commercially unimportant at the present time and do not provide service commensurate with the investment involved.

There are approximately 3,978 miles of the entire contemplated highway system not yet paved, of which amount 732 miles have been graded. Of this total, the following amounts are classified under the three types of roads already noted:

(1) Primary roads—1,540.4 miles.
(2) Secondary roads—818.6 miles.
(3) Roads providing little service—1,619.0 miles.

Your first concern is, of course, with the immediate program of construction and it seems to the writers that the order of precedence should closely follow the schedules of roads specifically contemplated under the successive bond issues. The three groupings showing the highways in detail appear in chapter 2 attached to the maps showing their location.

In other words, it is believed that first promises should receive priority in execution and the immediate concern should be the completion of those roads listed with Map No. 1 and proposed under the first bond issue.

We call attention specifically, also, to the immediate need for completing the gaps in the following main trunk lines:

1. Route 2—San Francisco to San Diego,
2. Route 3—Sacramento to Oregon Line,
3. Route 5—Stockton to Santa Cruz, via Oakland,
4. Route 1—San Francisco to Crescent City,
5. Route 12—San Diego to El Centro,
6. Route 8—Ignacio to Cordelia, via Napa

and those routes from 13 to 34 as yet incomplete. These highways constitute our classification of the roads of primary importance.

Secondary roads include the remaining so-called $3,000,000.00 laterals:

Route 10—Hanford to San Lucas,
Route 18—Mariposa to El Portal,
Route 20—Douglas City to Route 1, Arcata,
Route 27-28—San Bernardino to Yuma,
Route 31—San Bernardino to Barstow,
Route 32—Route 4 at Califa to Gilroy,
Route 33—Route 4 at Bakersfield to Paso Robles,

and there may be added to these:

Route 47—Orland to Chico,
Route 53—Rio Vista to Fairfield,
Route 57—Santa Maria to Bakersfield (Portion).

Roads of the third class, providing little commercial service and therefore of questionable financial return, include the remaining new highways added to the system by the third Highway Act. (See schedule attached to Map No. 3.)

Estimates made by the Highway Commission in April, 1919, covering incompleted sections, are found to be so low as to be of little service under present conditions. Some of the roads in these estimates have since been constructed and it is found that actual costs exceed the estimates from 20 to 30%. With the adoption of the 5-inch reinforced pavement as a minimum it is conservative to estimate that these estimates of 1919 are from 50 to 66⅔% too low. If proper thickness and widths of pavements for heavy traffic roads are adopted, it is apparent that these estimates must be considerably more than doubled to approximate a true forecast.

It is found that the cost of constructing 1,402 miles of paved highway to June 30, 1920, was in excess of $16,000.00 per mile; the greater portion of this work being performed prior to 1917. Concrete base during this early period averaged approximately $7.00 per cubic yard in place. This same concrete in 1920 is costing in excess of $17.00 per cubic yard in place.

The total remaining amount of highway to be paved is 3,978 miles. Even at the old figures which include the low prices prior to 1917, **this system completed would cost approximately $64,000,000.00. The absurdity of hoping even to approximate these former prices is too apparent to need comment.**

While a close degree of refinement in making estimates of this kind is difficult of attainment due to the variable conditions surrounding the work, it is possible to predicate an estimate on actual present day facts which will be closely approximate. Existing contracts for paved highway on the State system range from $20,000.00 to $40,000.00 per mile and these prices form the basis for the estimate following:

ESTIMATE

Primary Roads

808 miles to be graded and paved @ $35,000.00 average per mile	$28,280,000.00
732 miles already graded—to be paved @ $25,000.00 average per mile	18,300,000.00

Secondary Roads

818.6 miles to be graded and paved @ $30,000.00 average per mile	$24,558,000.00

Third Class Roads

1,619 miles—if graded only @ $15,000.00 average per mile	$24,285,000.00
If paved in addition, add 1,619 miles @ $25,000.00 average per mile	40,475,000.00

Bridges

Rough Approximation	$ 8,000,000.00
Grand total	$143,898,000.00

The moneys on hand with actual Federal aid contributions will therefore complete the primary roads but will leave no funds to construct any of the remaining 2,437 miles of highways provided for in the Highway Acts of 1915 and 1919.

General Summarization of Principal Recommendations 11.7

1. Increased authority to Division Engineers.
2. Re-classification of employees.
3. Improvement in cost data accounting.
4. Creation of equipment account.
5. More discriminating use of steel reinforcement.
6. Increased thickness of concrete road slabs.
7. Use of expansion joints to control buckling.
8. Further elimination of grade crossings and improvement of existing crossings.
9. Construction of experimental roads.
10. Increased width of paved roadway.
11. Increased ultimate strength of concrete.
12. Modification and enforcement of motor vehicle act.
13. Uniform procedure in the acceptance of county highway bridges.
14. Modification of State highway routings.
15. Aid to small municipalities.
16. Needed yearly traffic records.
17. Expanded research, experimental and laboratory work.
18. Restriction of day labor work.
19. Policy of co-operation with contractors.
20. Grade and curvature reductions.
21. Immediate road construction needs.

Conclusion 11.8

Before closing this report, it is timely to call attention to various phases of the difficulties confronting the California Highway Commission in the work undertaken.

The inadequacy of the original highway fund to accomplish the desired program presented a problem difficult of any satisfactory solution. A considerable mileage of hard paved highways has been given the people in spite of unsaleable four per cent highway bonds, and an important portion of the originally contemplated system has carried the burden of tremendously increased traffic for years.

Pavements of considerably more permanence than previously known on California highways have resulted from the work of the Commission and the savings effected on the purchase of cement, reduced freight rates, etc., have been notable.

Throughout the entire period of its activities, the administration of the California Highway Commission has been marked by scrupulous honesty and no question can be raised as to the earnestness and integrity of effort made to accomplish the best results for the expenditures.

In conclusion we wish to express our appreciation of the courtesy shown by the Commission in making available all records and data for examination and for the considerable amount of information, maps and other records furnished during the progress of this investigation.

Acknowledgment

We take this opportunity to acknowledge the valuable assistance rendered by Professor Charles Derleth, Jr., in connection with research and experimental work and other features of this investigation, and we wish to include our appreciation of the valuable data furnished by Mr. J. B. Lippincott, Consulting Engineer for the Automobile Club of Southern California.

ESTIMATE SHEET
PORTLAND CEMENT CONCRETE BASE
WIDTH 15 FEET.

PRICES:- **CONSTRUCTION MATERIALS**

CEMENT = $ 3.00 PER BARREL F.O.B. CARS SIDING.
ROCK = 1.50 PER TON " " "
SAND = 1.25 " " " "
STEEL (REINFORCEMENT)– 3/8" BARS– $ 5.00 PER 100#
F.O.B. CARS SIDING.
LUMBER (HEADERS)–2"x4", 2"x6"– $45.00 PER 1000 F.B.M
F.O.B. CARS SIDING

LABOR:–

FOREMEN = $ 8.00 TO $ 10.00 PER DAY.
MIXERMEN = $ 8.00 PER DAY.
BLACKSMITH = $ 9.00 " "
ROLLERMEN = $ 8.00 TO $ 10.00 PER DAY.
FINISHER = $ 8.00 PER DAY.
CARPENTER = 8.00 " "
TAMPERMEN = 7.00 " "
SHOVELERS = 5.50 " "
WHEEL BARROWMEN = 5.00 " "
OTHER LABOR = 5.00 " "

REMARKS=

THE ABOVE WAGE SCHEDULE AND PRICES ARE OF 1920.

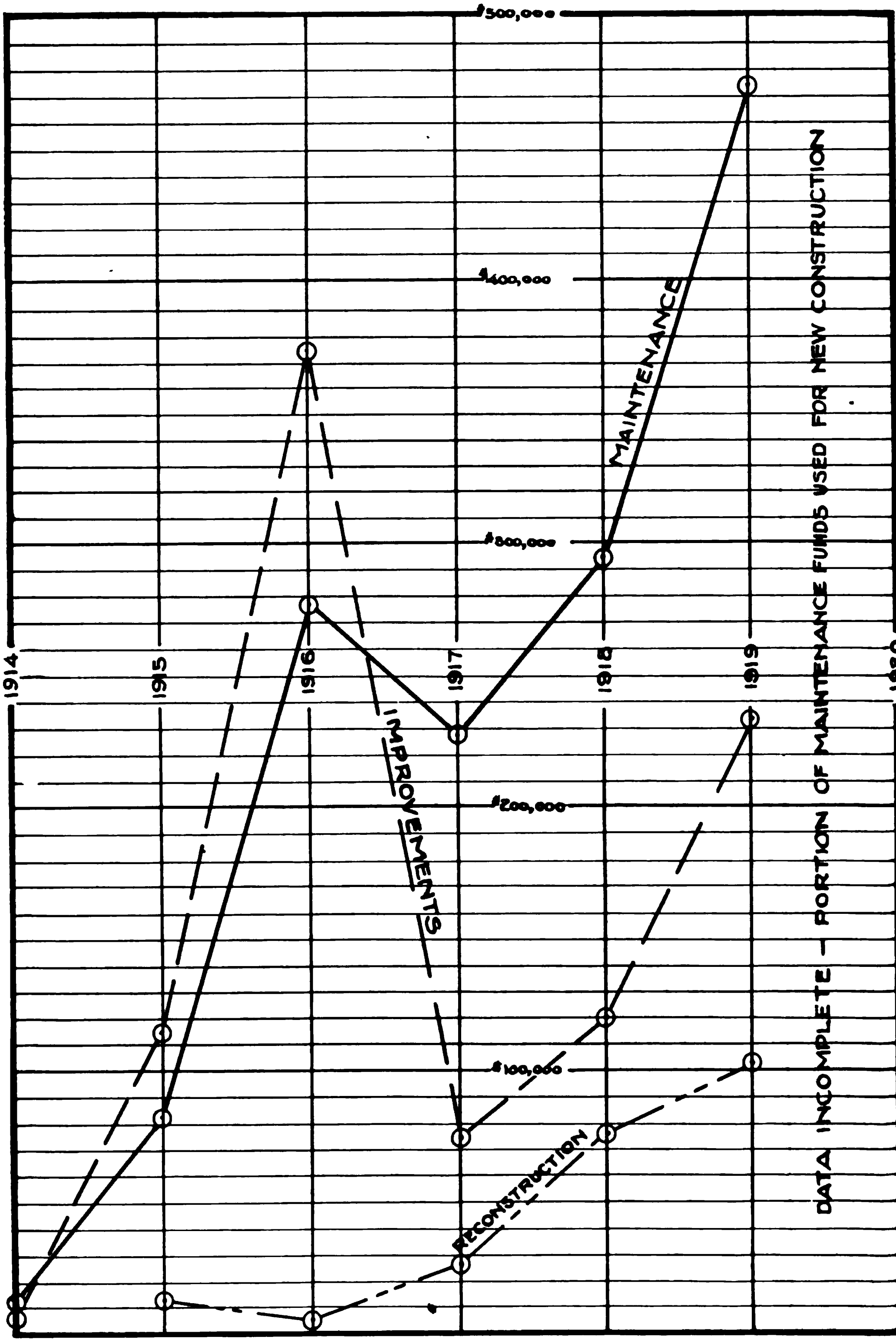
THEY ARE TENTATIVE ONLY AND WILL FLUCTUATE WITH THE PARTICULAR JOB.

ESTIMATE SHEET
PORTLAND CEMENT CONCRETE BASE
WIDTH 15 FEET.

1: 2: 4 MIXTURE

	PRICE PER CUBIC YARD 4"	5"	6"
1. CEMENT.			
PER BARREL F.O.B. SIDING $3.00 — UNLOADING 30¢ PER TON — HAULING ONE MILE AT 30¢ PER TON MILE — STORING AND CONSTRUCTION OR RENT OF SHEDS, SACK REJECTIONS ETC.	4.750	4.750	4.750
2. ROCK.			
PER TON F.O.B. SIDING $1.50 — UNLOADING 25¢ PER TON — HAULING 1.4 TONS AT 30¢ PER TON MILE — STOCKPILING, BUNKERS, SPUR TRACKS AND DEMURRAGE.	2.920	2.920	2.920
3. SAND.			
PER TON F.O.B. SIDING 1.25 — UNLOADING 25¢ PER TON — HAULING .7 TON ONE MILE AT 30¢ PER TON MILE — STOCKPILING, BUNKERS, SPUR TRACK AND DEMURRAGE.	1.315	1.315	1.315
4. WATER			
ESTIMATE BASED ON 300 GALLONS PER CUBIC YARD OF PAVEMENT INCLUDING 440 GALLONS FOR CURING AND WETTING SUBGRADE.			
HAULING AND INSTALLING PUMP AND ENGINE 2 TIMES; " " " PIPE LINE AND FITTINGS 2 TIMES; AND PUMPING (SUPPLIES AND LABOR)	.200	.200	.200
5. HEADERS.			
M. FEET R.O.R. AT $45.00 — 1. =	.146	.161	.132
HANDLING & HAULING — 2. =	.011	.018	.011
LABOR CARPENTER & HELPER — 3. =	.140	.112	.093
REDUCE No 1 2/3 ON ORDINARY WORK WHERE LUMBER WILL BE USED 3 TIMES.			
6. SUBGRADE			
TRIMMING, SPRINKLING, HARROW AND ROLL.	1.000	.800	.665
7. MANIPULATION			
MIXING, PLACING, TAMPING AND FINISHING.	1.250	1.250	1.250
8. CURING			
BUILDING DYKES, COVERING AND WATERING 10 DAYS (LABOR ONLY)	.270	.216	.180
TOTAL (LABOR & MATERIALS)	12.002	11.742	11.516
9. PROFIT (ON LABOR AND MATERIALS) 15%	1.800	1.682	1.727
10. PLANT CHARGES			
REPAIRS, INTEREST, DEPRECIATION, FREIGHT 6%	.720	.705	.691
11. MISCELLANEOUS & CONTINGENCIES 10%	1.200	1.174	1.152
12. SUPERVISION & OVERHEAD 10%	1.200	1.174	1.152
13. CONTRACTOR'S BONDS & INSURANCE (1.5% & 5% ON LABOR)	.448	.429	.416
TOTAL PER CUBIC YARD	17.370	16.985	16.654
TOTAL PER SQUARE YARD	1.928	2.354	2.777

FIG. 2



CURVE SHOWING TOTAL EXPENDITURES FROM MAINTENANCE FUND.

TABLE XIV.

NUMBER OF CUBIC FEET OF CONCRETE PER LINEAL FOOT. IN ROAD SLABS OF VARYING WIDTH & DEPTH 15' TO 20'

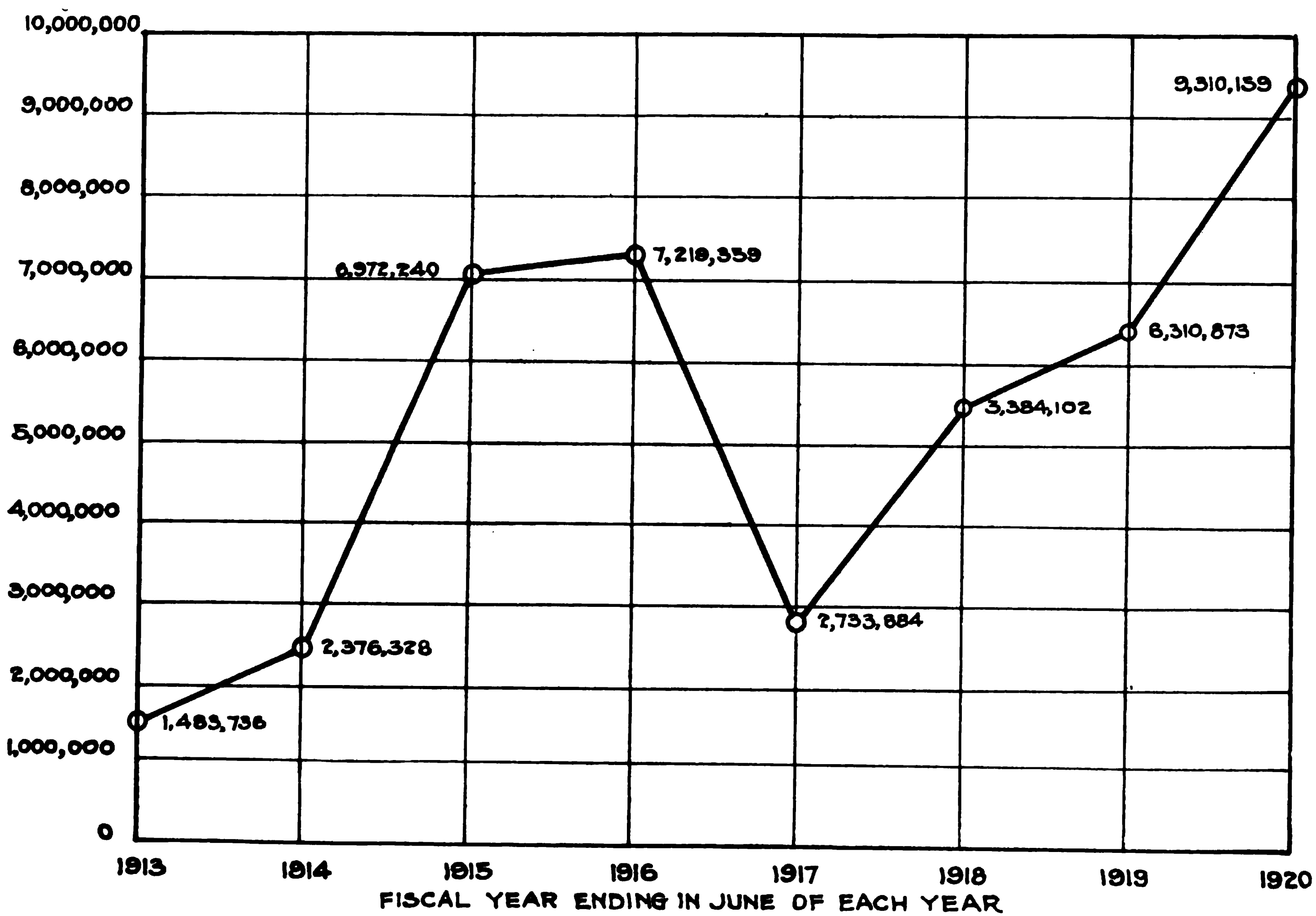
	Width of Road					
Depth of Slab	15'	16'	17'	18'	19'	20'
4" uniform	5.00	5.33	5.67	6.00	6.33	6.67
5" "	6.25	6.67	7.08	7.50	7.92	8.33
6" "	7.50	8.00	8.50	9.00	9.50	10.00
7" "	8.75	9.33	9.92	10.50	11.08	11.67
8" "	10.00	10.67	11.33	12.00	12.67	13.33

CUBIC YARDS OF CONCRETE PER 100' STATION

	Thickness of Slab				
Width in Feet	4"	5"	6"	7"	8"
15'	18.5	23.1	27.8	32.4	37.0
16'	19.7	24.7	29.6	34.6	39.5
17'	21.0	26.2	31.5	36.7	42.0
18'	22.2	27.8	33.3	38.9	44.4
19'	23.4	29.3	35.2	41.0	46.9
20'	24.7	30.9	37.0	43.2	49.4

FIGURE 6

CURVE OF TOTAL EXPENDITURES BY YEARS.



LABORATORY EXPERIMENTS

A PRELIMINARY STUDY OF ADOBE SOILS

AND

CONCRETE SLAB TESTS

FOR THE

CALIFORNIA STATE AUTOMOBILE ASSOCIATION

AND THE

AUTOMOBILE CLUB OF SOUTHERN CALIFORNIA

AS CONDUCTED AT THE

UNIVERSITY OF CALIFORNIA

BERKELEY, CALIFORNIA

UNDER THE DIRECTION OF

C. DERLETH, Jr.

Dean, College of Civil Engineering

C. T. WISKOCIL

Associate Professor of Civil Engineering

In Charge of Materials Testing Laboratory

UNIVERSITY OF CALIFORNIA

ADOBE SOIL TESTS

A PRELIMINARY STUDY

January 17, 1921
Made for
AUTOMOBILE CLUB OF SOUTHERN CALIFORNIA
CALIFORNIA STATE AUTOMOBILE ASSOCIATION

January 17, 1921.

Mr. J. B. Lippincott, Consulting Engineer,
Automobile Club of Southern California.
Mr. H. J. Brunnier, Chairman Highway Committee,
California State Automobile Association.

Gentlemen:

I submit our preliminary report on adobe soil tests. The inquiries were limited to the period September-December, 1920. Had more time been available, or had we felt justified in making greater expenditures by using a larger number of assistants, perhaps our report would have been more inclusive.

Our first studies and experiments were necessarily tentative and proved mostly negative. They showed us rather what not to do. As the tests proceeded, accumulating experience dictated changes in policy and program.

In our program of October 25, 1920 (presented herewith in Appendix A) we proposed four groups of tests; thus far we have limited our inquiries to the first of these groups, "Contraction and Expansion."

Tentative conclusions are outlined in the following preliminary study. These conclusions are spoken of as "tentative" because further studies, particularly on other samples of soils, may modify or enlarge our views.

Air dried adobe soils made into a stiff mud gave an average increase of 37% in volume; the same soils made into a paste that could be poured, gave an average of 67%. Assuming the specimens to have had the same rate of expansion in all directions, these volume increases respectively correspond to linear changes of 11% and 20%.

Experiments with fine sand and lime adulteration of adobe soil were limited in number. So far as our studies have proceeded, it would appear that adulteration with fine sand or lime does not greatly modify or reduce changes in volume due to changes in moisture content.

More numerous and elaborate tests under different conditions of adulteration (particularly with gravel and crushed rock) and with greater variety of samples of adobe soils may give more prominent effects. We had expected to find a greater reduction in volume changes from the addition of fine sand and lime, but our results thus far have not justified that expectation. The addition of sand and lime helps in the tilling of adobe soils by breaking up the material mechanically into smaller lumps. Further adulteration experimentation is needed but will require effort and considerable expenditure.

Tests were made to determine the amount of pressure required to increase the density of loose air dried adobe dust to that found in average air dried clods. Through the specially devised apparatus shown in Figure 5, a load of 6000 lbs. per sq. in. was applied to produce this result. This test raises the question of the efficiency of the ordinary highway steam roller. We would suggest further tests on roller pressures needed to produce a particular density in a given adobe soil. Samples of soils after treatment with a steam roller might with profit be studied.

In our laboratory experiments, after the confined adobe soil dust had been compacted to the density of natural clods under the high pressures just referred to, it was found that the specimen absorbed about 12% of water during a period of four days and that by absorbing the water it exerted an expansive pressure of 63 tons per sq. ft., or 880 lbs. per sq. in. Studies of this type are urged and may throw valuable light upon the heaving force of adobe soils under pavement slabs, or when otherwise confined, for different conditions of soil density, moisture content and lateral confinement.

Time did not permit the making of numerous tensile tests on adobe molded into briquettes or compressive tests on specimens molded into cylinders. We recommend further tests of this character.

Sieve analyses showed that the 13 different samples of adobe soil submitted from 5 counties were decidedly not uniform in grain size or sand content. A study of the grain size of the finer particles is strongly recommended.

Had time and money been available we should have proceeded to more elaborate full sized tests, particularly upon bearing power of soils (such as are described in Nos. II and III of our program of October 25, 1920). Just how that program as stated would be modified in the light of accumulating experience we leave to conjecture and future study.

In conclusion we cannot urge too strongly the continuance of these inquiries.

Truly yours,

C. DERLETH, Jr.

January 15, 1921.

Professor Charles Derleth, Jr.,
Dean College of Civil Engineering,
Campus.

Dear Professor Derleth:

In accordance with the directions in your letter of September 2, 1920, I have made a preliminary study of the important physical properties of some California adobe soils.

The progress was slow because it was necessary to devise and test methods of procedure before active work could be begun. The experiments on volume changes (expansion and contraction) were given most consideration because of the importance of the information to be secured. These data, therefore, constitute the largest part of the report.

The results of the volume-change tests as well as the other experiments are interesting and valuable, but in no case are they conclusive. Nevertheless, they are an excellent foundation for further investigation.

It would be unwise to make, from these incomplete data, any general conclusions or to construct a hypothesis regarding the volume changes in adobe soils. It is proper, however, to summarize the results obtained and emphasize the fact that the following statements apply only to the particular soils studied:

1. Adobe soils increase 1½% in volume from oven to air-dry conditions.
2. Air-dry adobe soils contain about 6% water.
3. Air-dry adobe soil when made into a stiff mud (a condition of plasticity not easily defined) will increase 37% in volume. (The range for the soils used was from 16% to 51%.)
4. Air-dry adobe soils made into a paste that could be poured will increase 67% in volume. (The range was from 28% to 93%.)
5. Different soils require different percentages of water to bring them to the same degree of plasticity.
6. Sand is not very effective in reducing volume changes in adobe soils.
7. A pressure of 430 tons per square foot was required to compact loose, air-dry, adobe soil to the density of air-dry clods (as found).
8. Confined adobe soil compacted to the density of the natural clods absorbed 12% water; its inability to increase in volume produced a pressure of 63 tons per square foot. (126,000 lbs. per sq. ft.)
9. The tensile strength of a specimen of adobe soil, taken at random, was 270 lbs. per sq. in.
10. The compressive strength of a specimen similarly taken was 2,500 lbs. per sq. in.
11. Soils classified as adobe show marked variation in grain size.

A complete description of the methods used and the details of the results secured are given in the attached report.

Respectfully submitted,

C. T. WISKOCIL,
Associate Professor of Civil Engineering, in
Charge of Materials, Testing Laboratory.

CTW*C

TABLE OF CONTENTS

TABLE OF CONTENTS — Continued

A PRELIMINARY STUDY OF CERTAIN CALIFORNIA ADOBE SOILS

Adobe is a term applied to certain California soils, which, when wet are very plastic and when dry are excessively cracked, the individual clods being hard and tough. Figure 1 shows a characteristic soil of this type in its dry state.

Figure 1. Looking down on an enamel-ware pan of dry adobe soil.

Adobe soils, because of their large volume changes under various moisture conditions, form poor subgrades for permanent highways. The present study was undertaken to secure data on these volume changes or amounts of expansion and contraction—as they are fre-

quently called. The following table gives the county from which the various soils were received.

Table I

TYPICAL CALIFORNIA ADOBE SOILS

Sample Number	Submitted by	County
1	Howe & Peters	Butte
2, 3, 4	Jones	Los Angeles
5, 6, 7	O'Neill	Santa Barbara
8, 9, 10	Moye	Tulare
11, 12, 13	Petit	Ventura

No information on adobe soils could be found in engineering publications available in the university library. It was necessary therefore, to proceed slowly and try out ideas and schemes before preparing a comprehensive program of investigation.

Since data on volume changes was the principal information desired, that work was given most attention. It was begun with actual volumetric determinations which were soon abandoned for linear shrinkage tests from which volumes could be computed. The linear shrinkage experiments were very satisfactory because it was possible to show moisture-volume relations for a range of values and also check determinations made by actual volume measurements. These tests were therefore made on all soils sent to the laboratory. The Butte County soil was then used to determine the effects of lime and sand on volume changes. When this work was well under way the moisture content, specific weights and sieve analyses were made for each soil. A few specimens were then prepared so that an idea of the tensile and compressive strengths of adobe could be obtained. The last experiments made were probably the most interesting because one served to substantiate, by actual expansion tests, the expansions computed from linear shrinkage tests, while the other showed that confined adobe soil exerted a very high pressure when it absorbed water.

Figure 2. Apparatus and test specimen used to determine the expansion of adobe soil.

Expansion—Actual.

A cylindric specimen was cut, in a lathe, from a lump of soil, No. 12, from Ventura County. The apparatus is shown in Figure 2. The specimen of soil was fitted into the porous (Alundum) thimble and the metal plunger placed on the soil. The thimble was then put into a beaker of water and the raising of the plunger measured.

Expansion—Computed from linear shrinkage tests.

Tests that could be quite easily made and yet yield considerable information were required. The linear shrinkage experiments satisfied these requirements. Strings of mud about ½-inch by ½-inch by 30 inches were made up of a representative sample of each soil as received. Each sample was mixed to approximately the same consistency which required about 30%, by weight, of water. The exact amount of water used for each soil is shown on Plates III to IX inclusive. The molded specimens were placed in grooved boards and measurements between two gauge marks on each end of the string (the name given to these specimens) immediately begun. Three strings were made up of each soil; two were measured while pieces of the third were dried to determine moisture content corresponding to every measurement of length. The boards and strings of soil are in the background of Figure 3 together with four small pans with moisture specimens.

Expansion—Computed from volumetric tests.

Two sets of volume determinations were made using the soils after they had been passed through a 100-mesh sieve. In the first set the soil was mixed with about 30% water and molded by hand into cylindric specimens whose volume was approximately 2.0 cu. in. These specimens are in the left of Figure 6. Each specimen was weighed in air and again in kerosene. These original measurements together with similar measurements taken after the specimens had been dried in air for about a week and later in an oven, maintained at 100° C., to constant weight were used to determine the change in volume.

The second set of volume determinations were made with more plastic mud. The soils were mixed with about 60% water and poured into tin cups whose volume was about 23

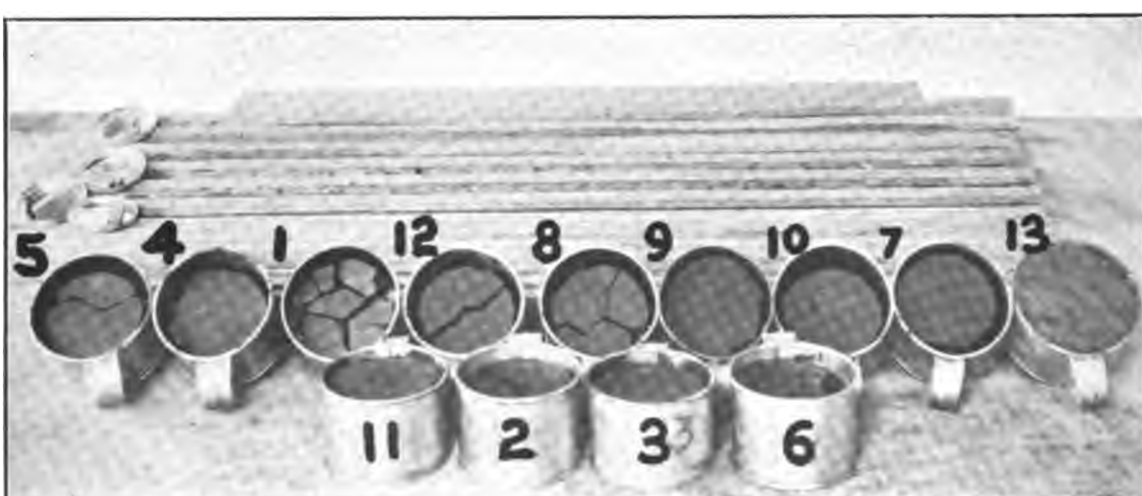


Figure 3. Volume changes due to drying thin mud of adobe soil. Cup at right end refilled with water to show original appearance of specimens. Linear shrinkage tests in background.

cu. in. The exact volume of each cup had been previously determined. The specimens were weighed and set aside to dry. After being oven dried they were again weighed and the decrease in volume of the specimen determined by weighing the kerosene required to fill the cups after the specimens had become saturated. The cup experiments are in the foreground of Figure 3.

Expansion—Effect of lime and sand.

The experiments to determine the effect of lime and sand on the volume changes in adobe soils were carried out on the sample from Butte County. The specimens were the linear-shrinkage strings previously described. Additions of 10, 20, and 40% sand and 1 and 5% lime were used. The tests were similar to those already described.

Expansive Force in confined adobe soil as affected by absorbed water.

The difficulty of confining wet adobe under pressure was clearly recognized before this experiment was begun. An apparatus which had been previously used to remove water (the soil solution) from very fine-grained soils—all passing a 200-mesh sieve—was set up as in Figure 5. It is shown in cross-section in Figure 4.

Powdered soil, Butte County adobe soil, was passed through a 100-mesh sieve and put into the cylinder. A pressure of 6,000 lbs. was applied. This load was required to compact the soil to the density of the clods as found. The load was decreased to 32 lbs. per sq. in. and the water was then poured into the funnel. It saturated the sand which completely surrounded the soil. A one-foot head of water was maintained on the specimen throughout the test. The increase in soil pressure or expansive force is shown in Plate XIII.

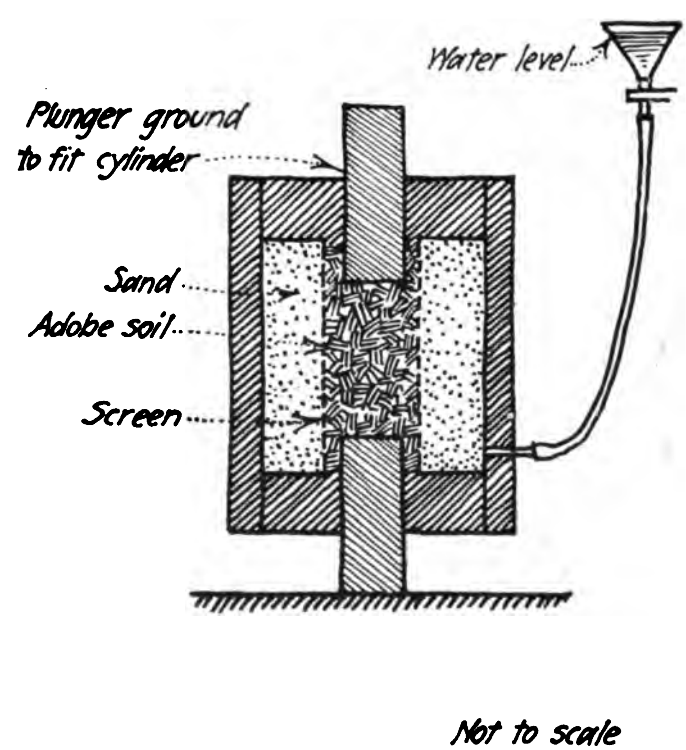


Figure 4. Cross-section of apparatus shown in Figure 5.

After the test the specimen was removed and its moisture content determined. The specimen of soil, after being dried, is shown in Figure 5; it is in the middle foreground. The screen, made of perforated brass, is at the left. The lower plunger is not shown in the photograph.

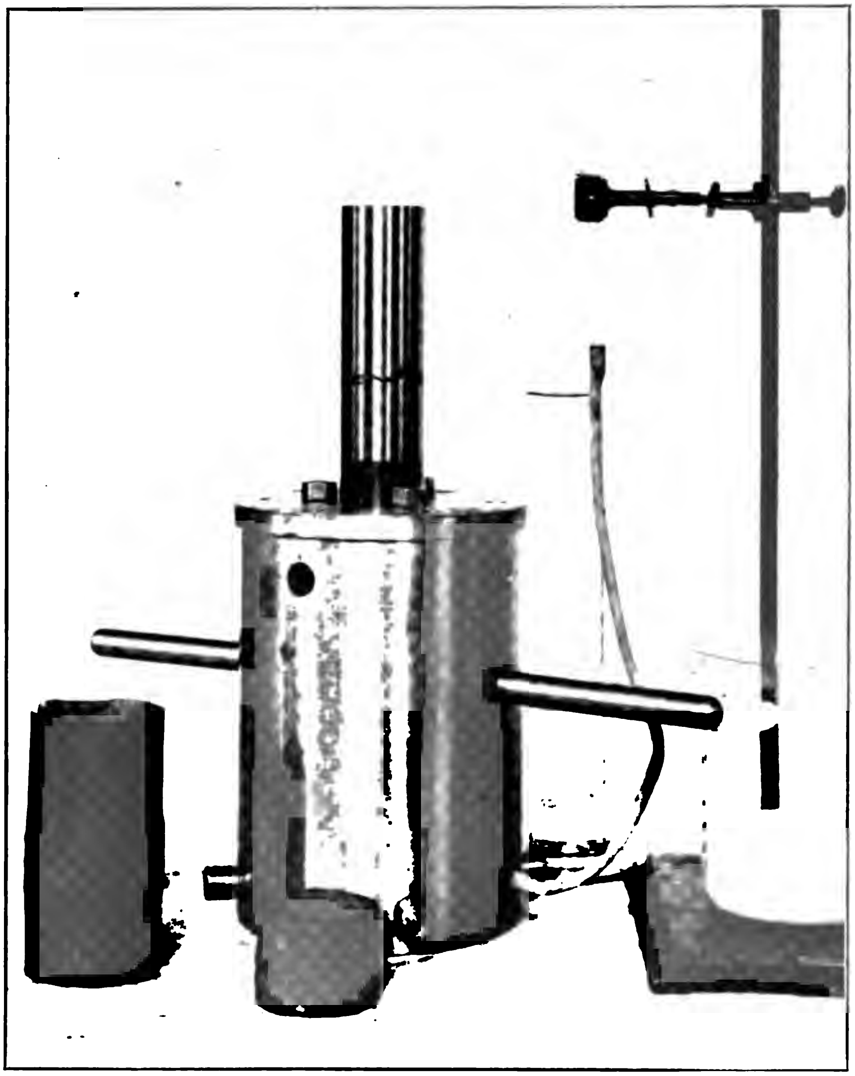


Figure 5. Apparatus and test specimen used to determine expansive force of adobe soil.

Moisture Content

The moisture content of air-dry adobe soil was obtained by drying to a constant weight in an oven maintained at 100 degrees Centigrade. The details are given in Table II. The small lumps are shown at the right in Figure 6. One of the large lumps is in the middle background in the same figure.

Figure 6. Test specimens of adobe soil.

Sieve Analyses

A 500-gram sample of each soil was used. It was placed on a 200-mesh sieve and washed with water. The soil passing the sieve was rejected and that remaining on it was dried and screened through coarser sieves as indicated in Table III. The relative amounts of the original sample (the two jars to the left in the photograph) and the material retained on a 200-mesh sieve are shown in Figure 7.

The grain size of the material passing a 200-mesh sieve was not determined for lack of time.

Specific Weight

The weights of adobe soils in lbs. per cu. ft. are given in Table IV. The volumes of separate pieces were determined and the specific weights computed. The 2 cu. in. lumps were coated with paraffin and weighed in water; they are shown in the middle foreground in Figure 6. The other weights were computed from the volumetric-shrinkage data with the exception of the average material which was shoveled into a ½ cu. ft. measuring box and jarred so as to completely fill the box.

Strength

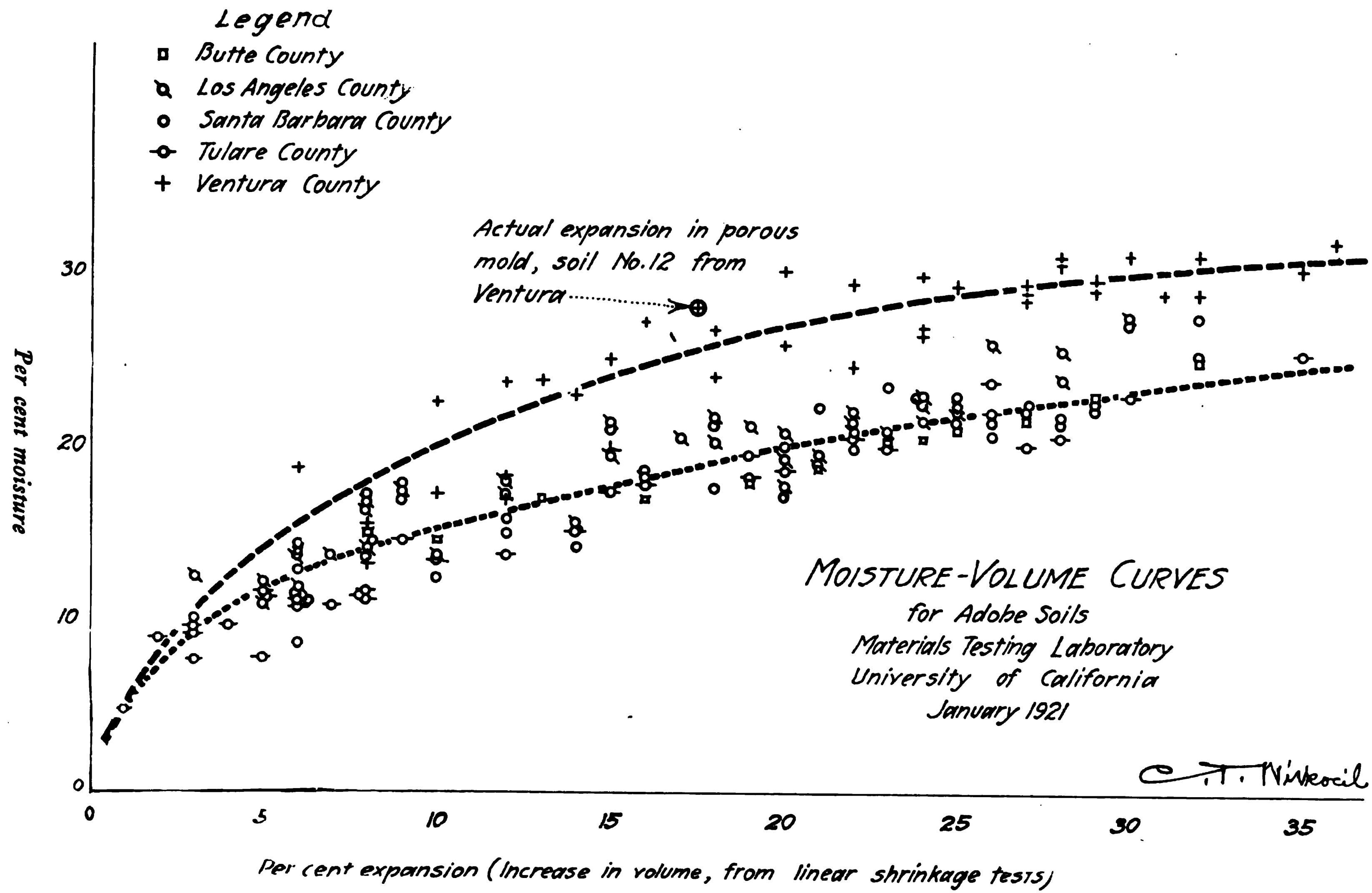
Four briquettes were molded with different soil-pastes taken at random when the volume-shrinkage test specimens were being prepared. They were tested after being thoroughly air-dried.

A mixture of different soils made into a paste was used to try out the gun shown in Figure 8 (page 40). Several specimens were prepared; the one to the left in the photograph was cut to a length of 1.2 in. so that the ends were plane and parallel to each other. Its diameter was 0.9 in. The specimen was thoroughly air-dry when tested in compression.

RESULTS

The results are given in the following tables and plates in the order indicated in the Table of Contents.

Plate I



Legend
Butte County
Los Angeles County
Santa Barbara County
Tulare County
Ventura County
Actual expansion in porous mold, soil No. 12 from Ventura
MOISTURE-VOLUME CURVES
for Adobe Soils
Materials Testing Laboratory
University of California
January 1921
C. T. Nikkocil
Per cent moisture
0
10
20
30
0
5
10
15
20
25
30
35
Per cent expansion (Increase in volume, from linear shrinkage tests)

Plate II

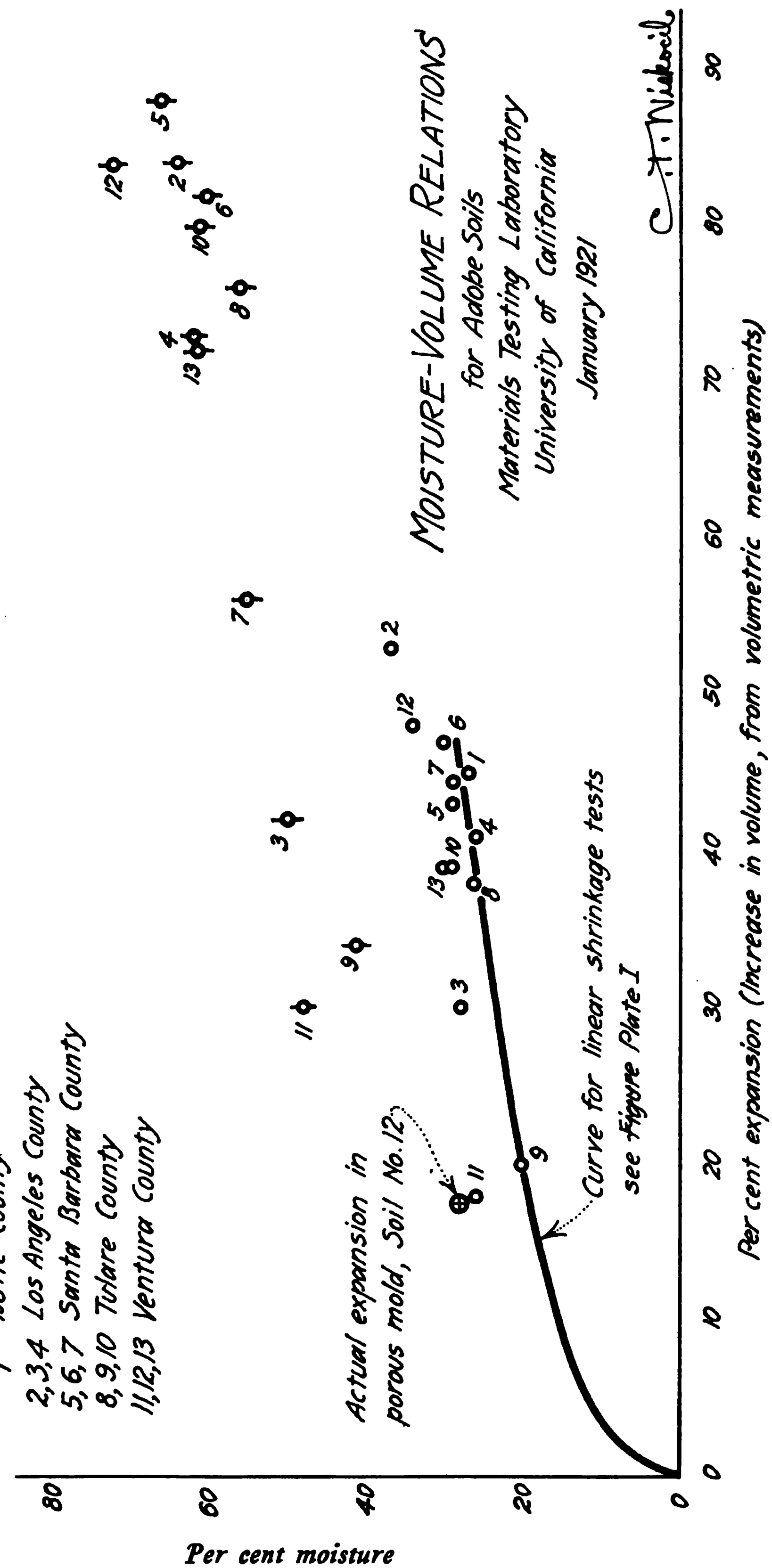

Legend
Molded specimens (thick mud)
Poured specimens (thin mud)
1 Butte County
2,3,4 Los Angeles County
5,6,7 Santa Barbara County
8,9,10 Tulare County
11,12,13 Ventura County
Actual expansion in porous mold, Soil No. 12
Curve for linear shrinkage tests
see ~~Figure~~ Plate I
MOISTURE-VOLUME RELATIONS
for Adobe Soils
Materials Testing Laboratory
University of California
January 1921
Per cent expansion (Increase in volume, from volumetric measurements)
0 10 20 30 40 50 60 70 80 90
0 20 40 60 80
Per cent moisture

Table II. Moisture Content of Air-Dry Adobe Soil

Sample	Small Lumps	Large Lumps	Passing 100 Mesh Sieve	Average Material
1	5.7	....	6.0	6.2
2	6.1	....	6.7	5.8
3	5.8	....	4.0	5.9
4	6.0	....	5.4	5.5
5	6.4	5.7	6.3	5.1
6	6.8	6.0	5.8	6.0
7	4.8	4.7	5.3	5.1
8	5.4	....	6.2	4.2
9	2.5	....	3.7	2.0
10	6.8	....	6.5	4.5
11	4.6	....	3.6	5.1
12	7.5	....	6.5	7.3
13	6.1	....	6.7	7.3

Volume of small lumps about 7 cu. in.

Volume of large lumps about 240 cu. in.

Average material was a mixture of dust and lumps, none of which were larger than 2 cu. in.

Table III. Sieve Analyses of Adobe Soils

Cumulative weights of soil retained on given sieve, expressed in percentage of total weight of sample.

Size of openings in sieve, in mm. Number of openings per inch (mesh)	4.70 4	2.36 8	1.17 14	0.59 28	0.30 48	0.15 100	0.07 200
Sample Number From							
1 Butte County	0	0	2	3	5	9	13
2 Los Angeles County	0	0	0	1	3	6	8
3 Los Angeles County	0	1	2	4	9	16	20
4 Los Angeles County	0	1	1	2	7	14	22
5 Santa Barbara	0	0	0	1	3	8	11
6 Santa Barbara	0	0	0	1	5	10	14
7 Santa Barbara	0	0	0	1	4	14	22
8 Tulare County	1	2	3	5	10	14	18
9 Tulare County	1	6	18	27	36	45	52
10 Tulare County	0	3	6	12	20	29	35
11 Ventura County	0	0	0	0	1	4	10
12 Ventura County	2	4	8	14	21	26	31
13 Ventura County	0	1	2	2	4	6	9
*Porterville Clay-Loam Adobe	0	0	4	13	17	24	31
Size of sieve openings, mm.	....	2.0	1.0	.50	.25	.10	.05

All samples passed a sieve having 3/8 in. openings.
*Soil Survey of Porterville Area, 1908 Field Operations of Bureau of Soils, page 1324.

Table IV. Weight of Adobe Soil in lbs. per cu. ft.

Natural Lumps		Average Mater'l	Test Specimens Oven-Dry	
Large Oven-Dry	Small Air-Dry	Air-Dry	Stiff Mud	Thin Paste
1 135	132	....	127	135
2 124	133	82	113	121
3 119	124	90	102	121
4 122	129	88	108	130
5 126	122	....	115	129
6 126	125	....	115	127
7 117	118	....	105	127
8 120	123	....	119	130
9 110	117	....	106	126
10 132	127	....	114	129
11 103	94	....	94	115
12 110	117	....	104	122
13 111	117	....	107	120

Volume of large natural lumps about 7 cu. in., kerosene method.
Volume of small natural lumps about 2 cu. in., paraffin method.
Volume of stiff mud specimens about 14 cu. in.
Volume of thin paste specimens about 1.5 cu. in.
All test specimens made of soil passing a 100-mesh sieve.

Table V. Volumetric Expansion, Computed from Shrinkage Tests

Soil Number	Thin Mud		Stiff Mud	
	% Water	% Expansion	% Water	% Expansion
1	53	95	27	45
2	64	84	37	53
3	50	42	28	30
4	62	73	26	41
5	66	88	29	44
6	60	82	30	47
7	55	56	29	44
8	56	76	26	38
9	41	34	20	20
10	61	80	29	39
11	48	30	24	18
12	72	84	34	48
13	61	72	30	39

Plate I

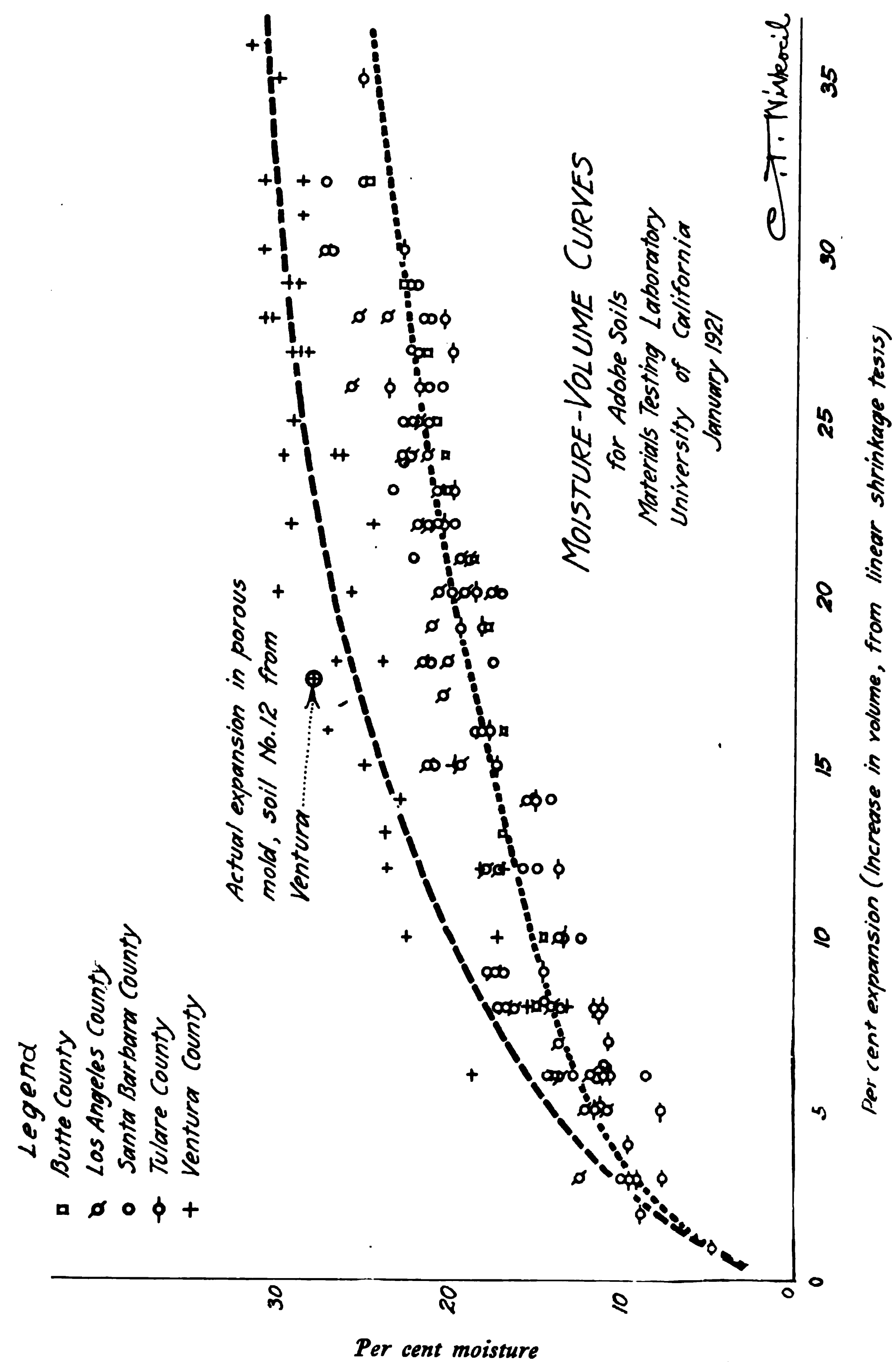
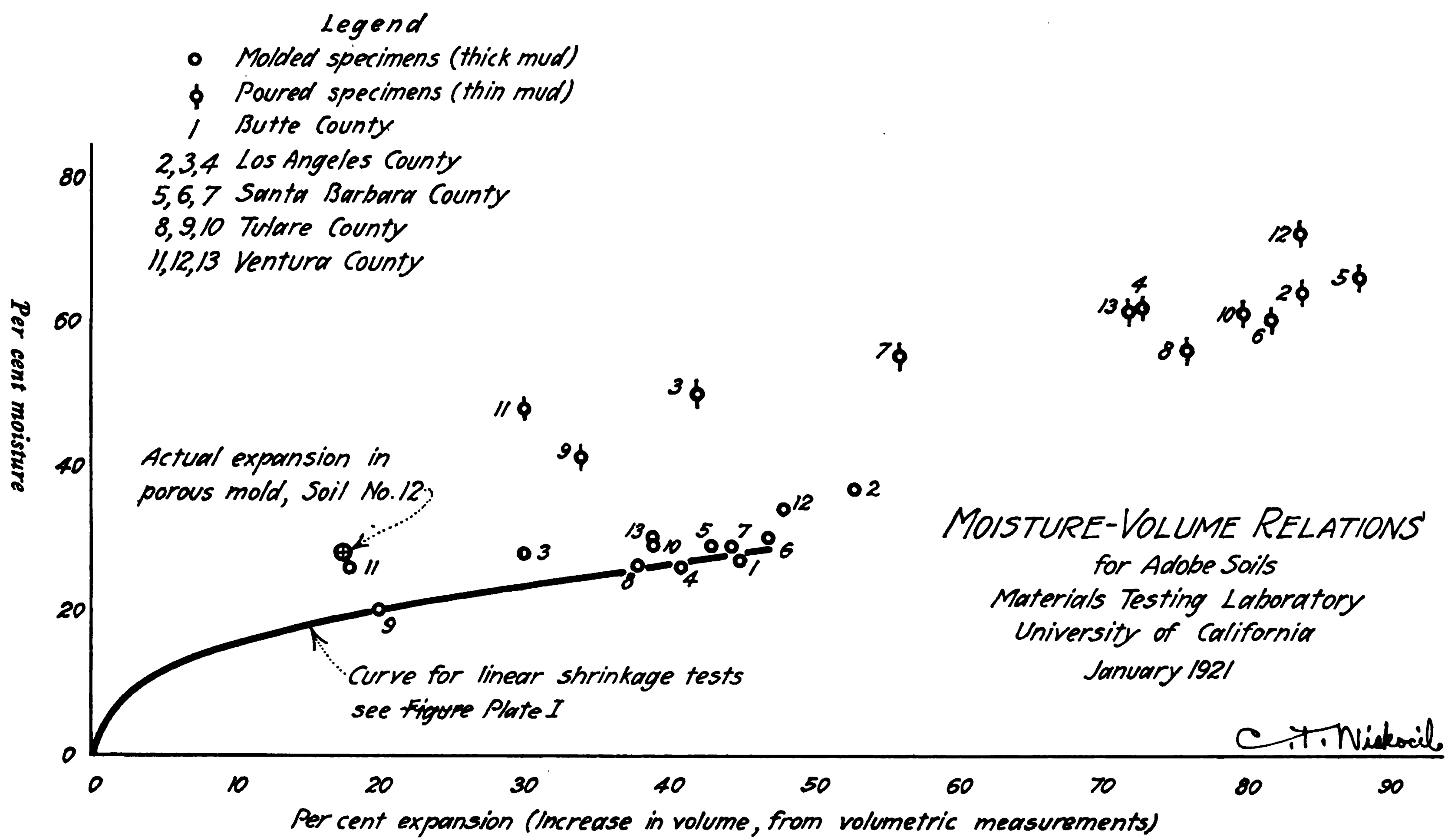

Legend
Butte County
Los Angeles County
Santa Barbara County
Tulare County
Ventura County
Actual expansion in porous mold, soil No. 12 from Ventura
MOISTURE-VOLUME CURVES
for Adobe Soils
Materials Testing Laboratory
University of California
January 1921
C. T. Wiskocil
0
5
10
15
20
25
30
35
10
20
30
Per cent expansion (Increase in volume, from linear shrinkage tests)
Per cent moisture

Plate II



Legend
Molded specimens (thick mud)
Poured specimens (thin mud)
1 Butte County
2,3,4 Los Angeles County
5,6,7 Santa Barbara County
8,9,10 Tulare County
11,12,13 Ventura County
Actual expansion in porous mold, Soil No. 12
Curve for linear shrinkage tests
see ~~Figure~~ Plate I
MOISTURE-VOLUME RELATIONS
for Adobe Soils
Materials Testing Laboratory
University of California
January 1921
C. A. Nickocil
0
10
20
30
40
50
60
70
80
90
Per cent expansion (Increase in volume, from volumetric measurements)
0
20
40
60
80
Per cent moisture

Plate III

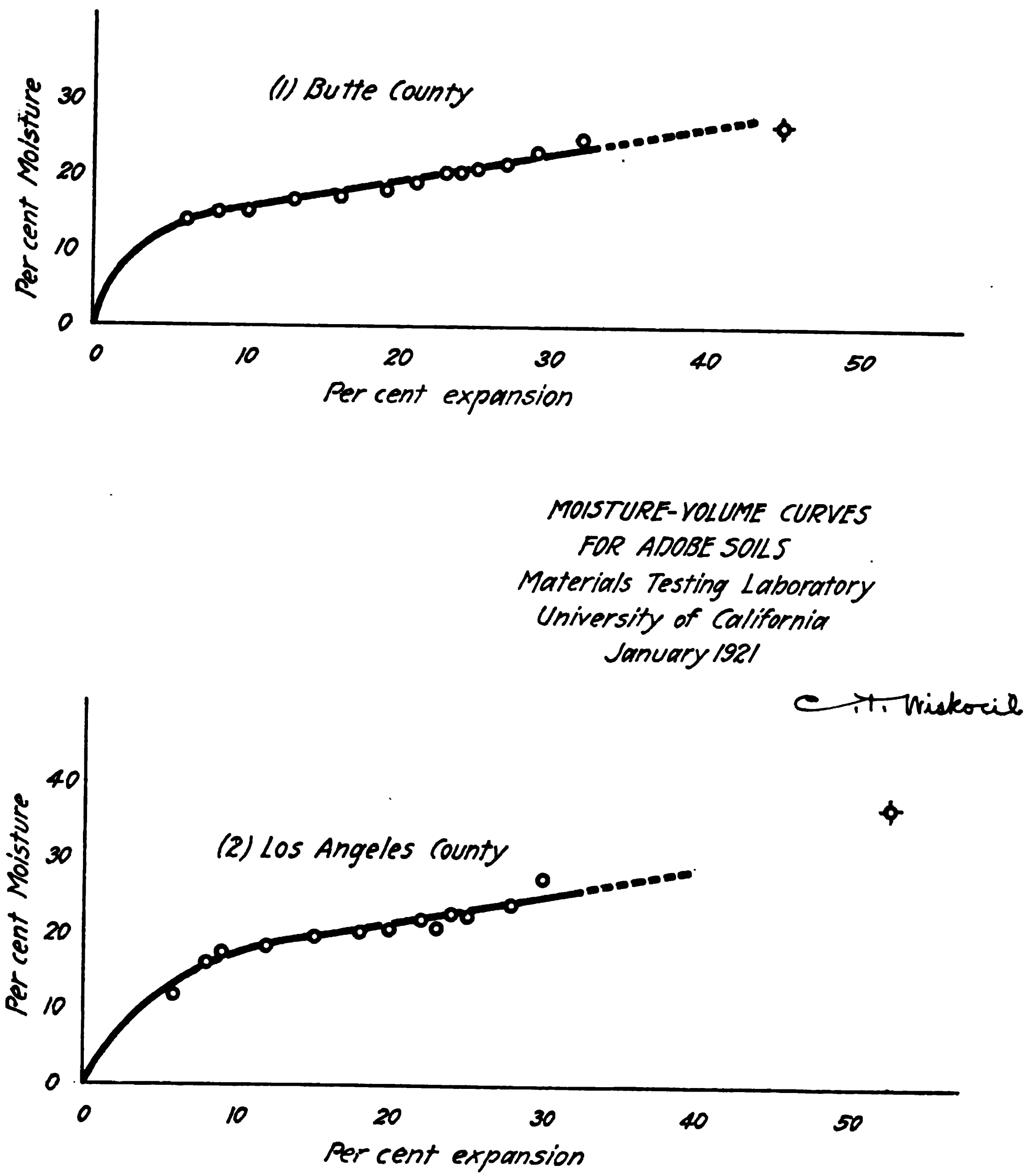
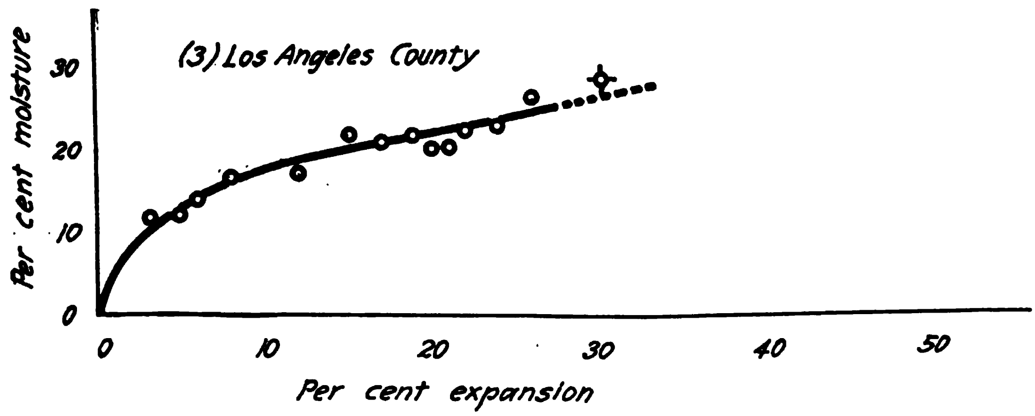

(1) Butte County
Per cent Moisture
0
10
20
30
0
10
20
30
40
50
Per cent expansion
MOISTURE-VOLUME CURVES
FOR ADOBE SOILS
Materials Testing Laboratory
University of California
January 1921
(2) Los Angeles County
Per cent Moisture
0
10
20
30
40
0
10
20
30
40
50
Per cent expansion

Plate IV



MOISTURE-VOLUME CURVES
FOR ADOBE SOILS
Materials Testing Laboratory
University of California
January 1921

C. T. Wiskocil

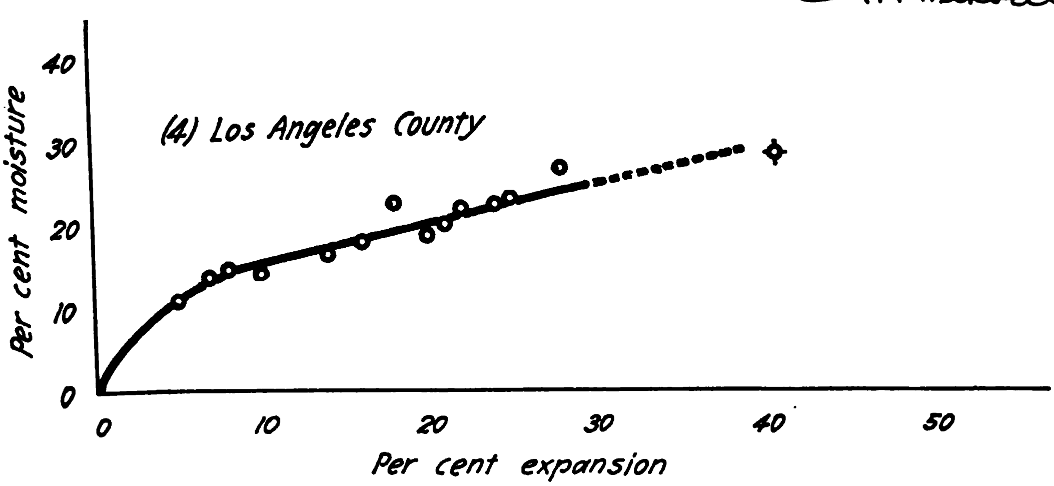
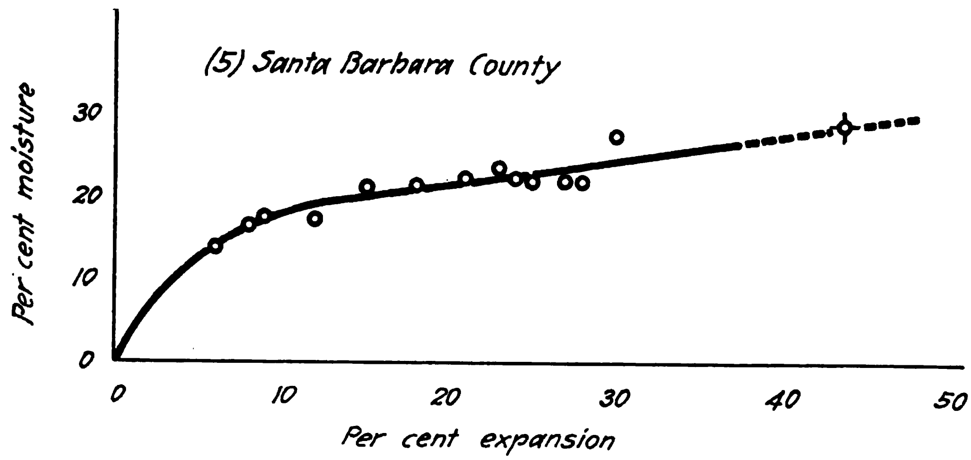


Plate V



MOISTURE-VOLUME CURVES
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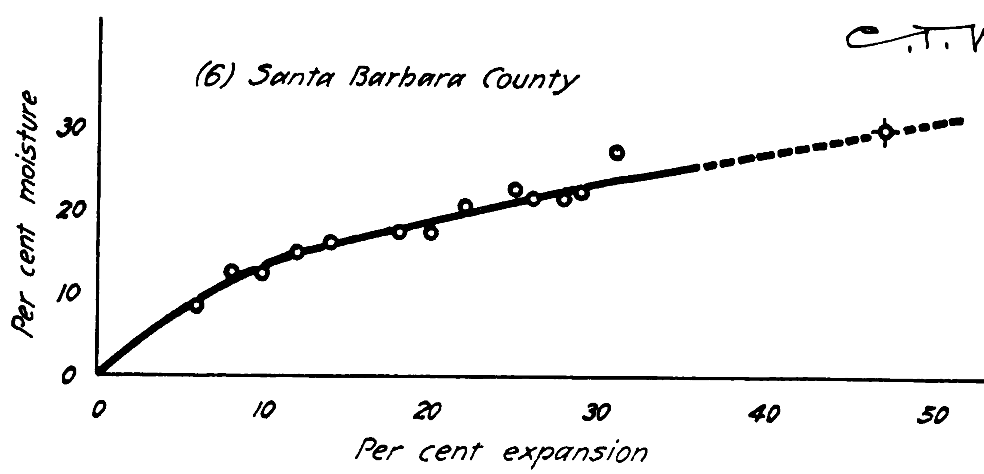
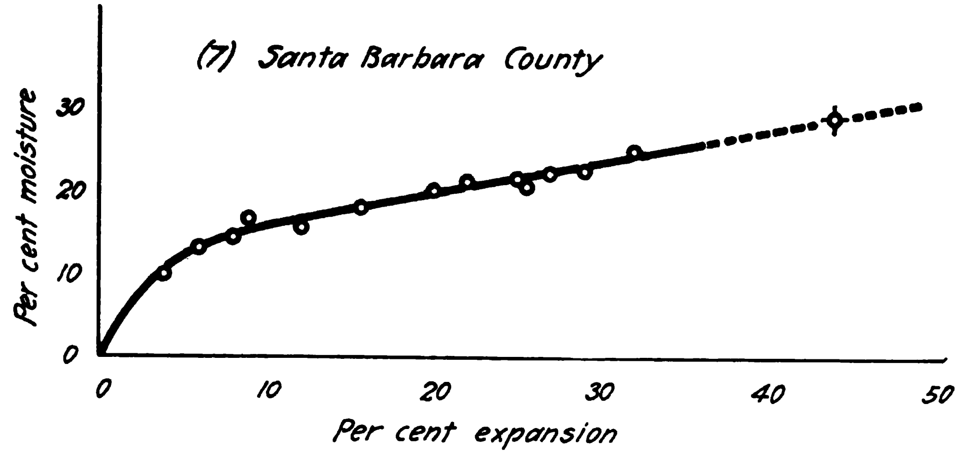


Plate VI



MOISTURE-VOLUME CURVES
FOR ADOBE SOILS
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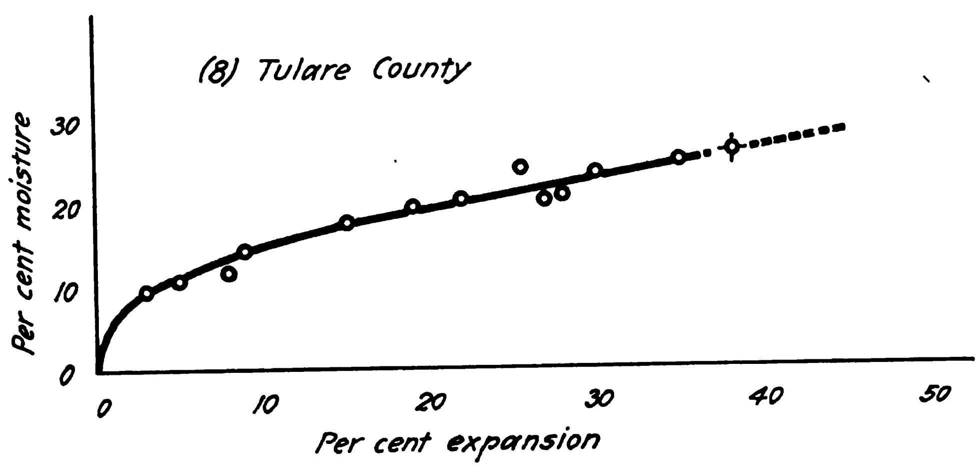
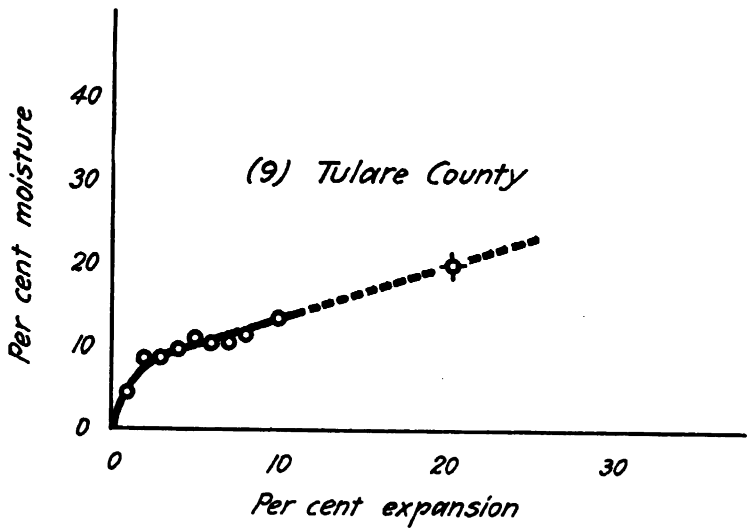


Plate VII



MOISTURE-VOLUME CURVES
FOR ADOBE SOILS
Materials Testing Laboratory
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January 1921

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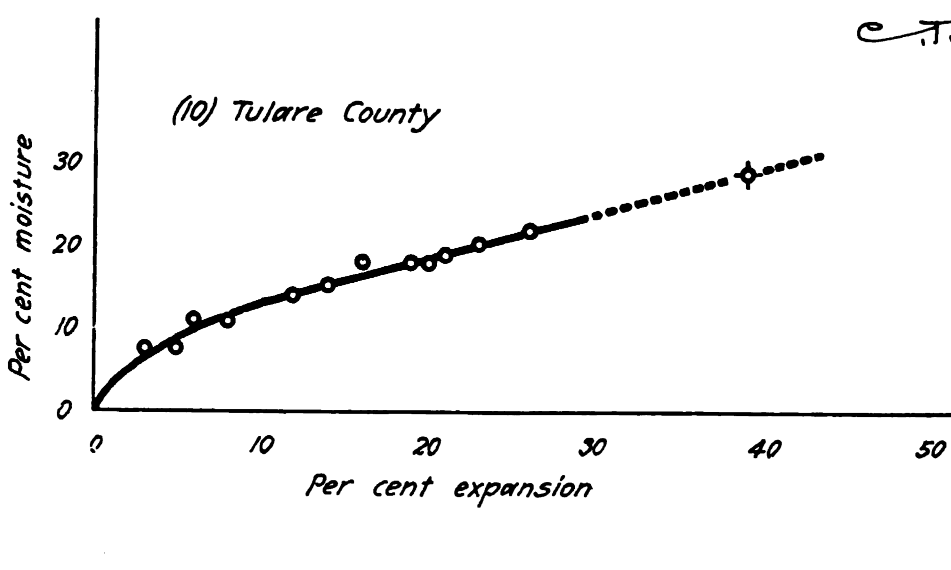
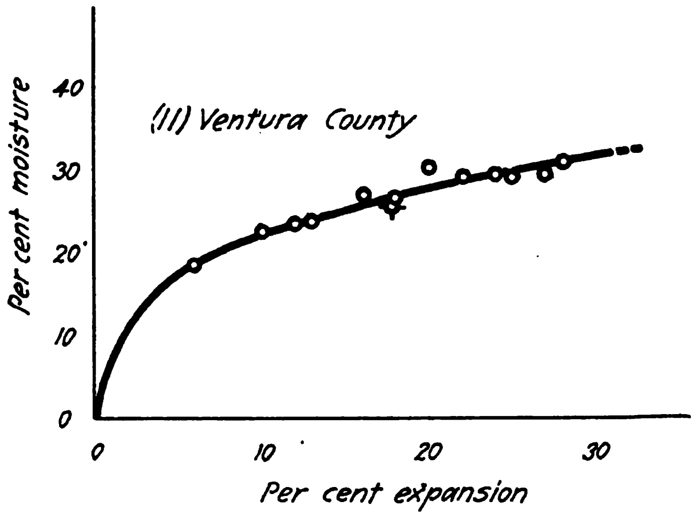


Plate VIII



MOISTURE-VOLUME CURVES
FOR ADOBE SOILS
Materials Testing Laboratory
University of California
January 1921

C. T. Wiskocil

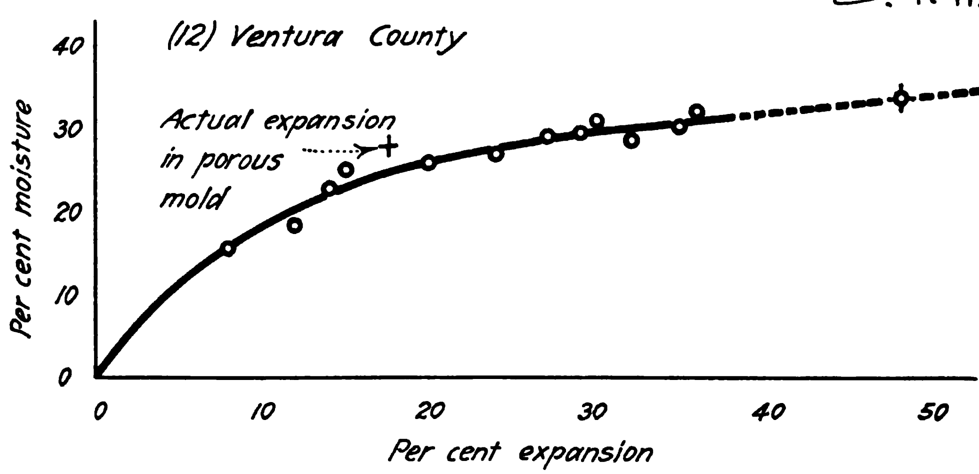
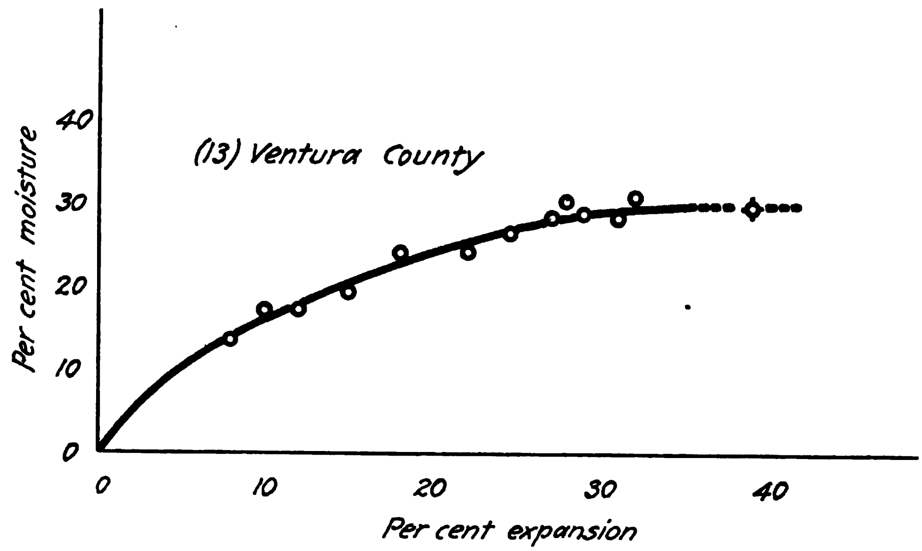


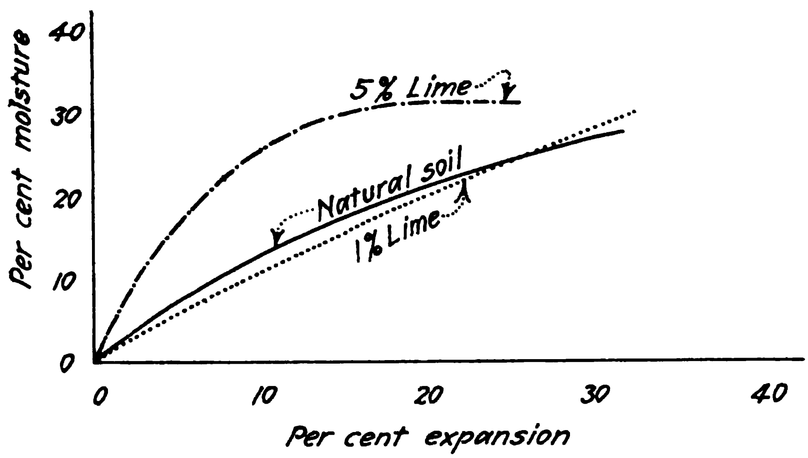
Plate IX



MOISTURE-VOLUME CURVES
FOR ADOBE SOILS
Materials Testing Laboratory
University of California
January 1921

C. T. Wiskocil

Plate X



EFFECT OF LIME AND SAND
ON MOISTURE-VOLUME RELATIONS
OF BUTTE COUNTY ADOBE SOIL

Materials Testing Laboratory
University of California
January 1921

C. T. Wiskocil

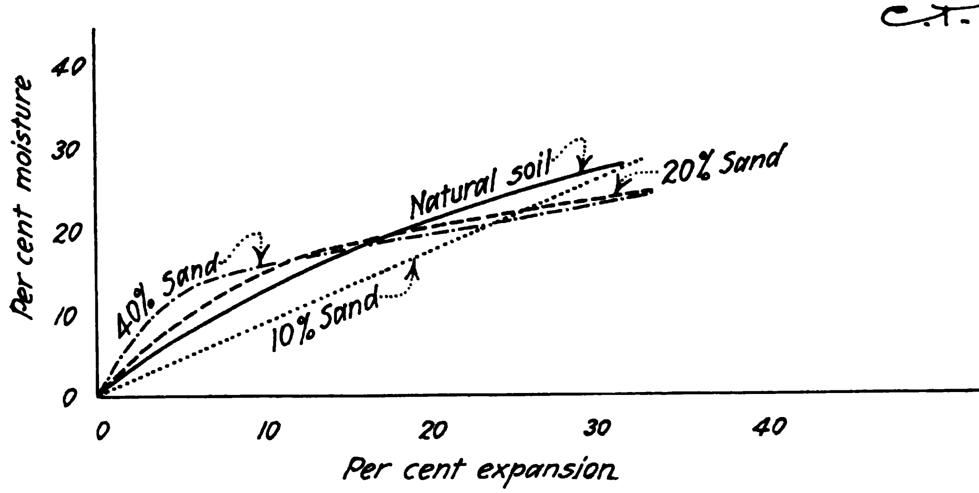
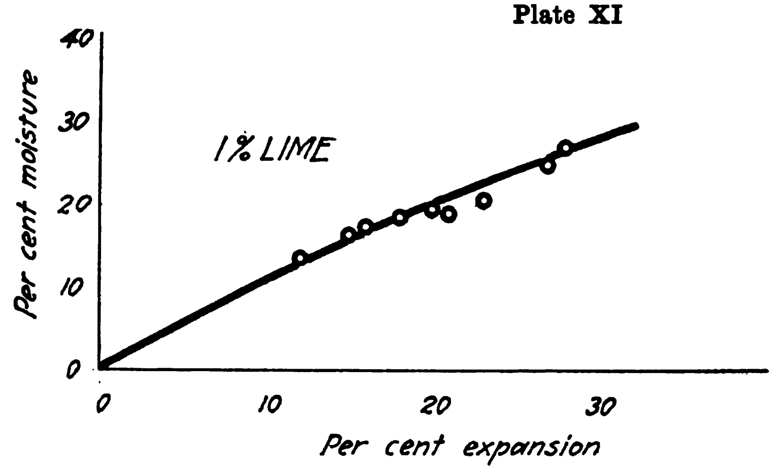
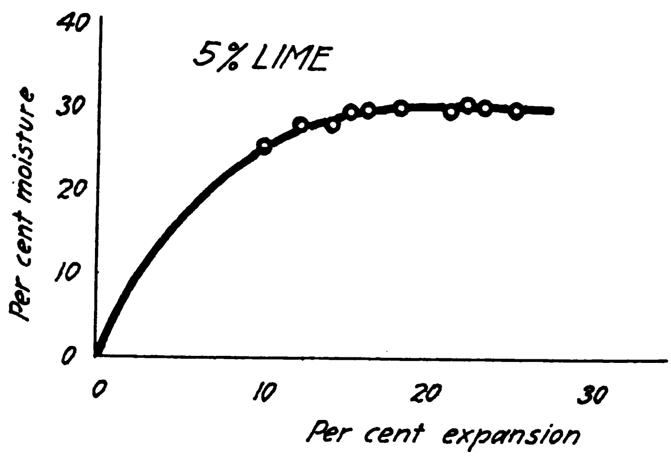
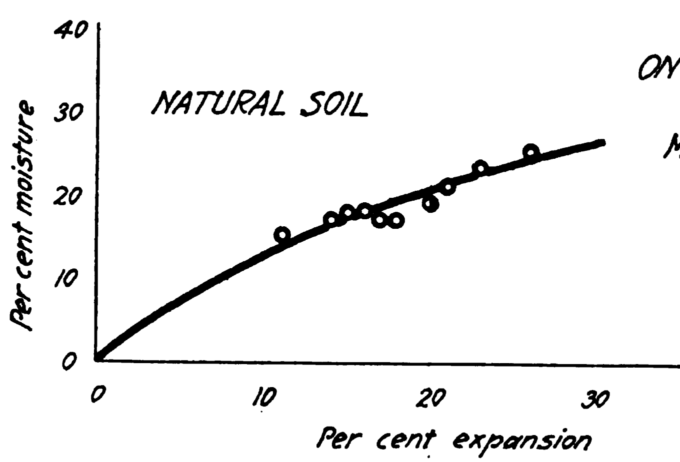


Plate XI



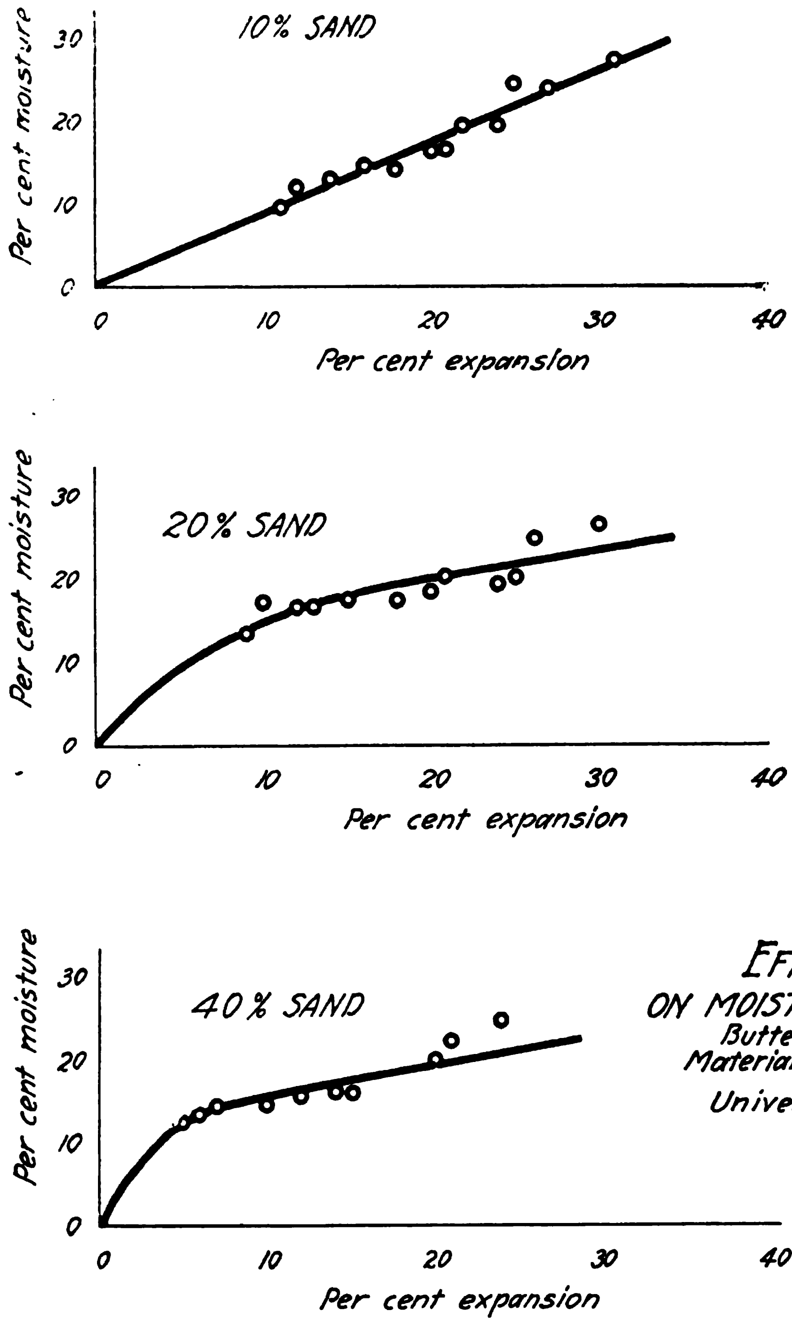




EFFECT OF LIME
ON MOISTURE-VOLUME RELATIONS
Butte County Adobe Soil
Materials Testing Laboratory
University of California
January 1921

C. T. Wiskocil

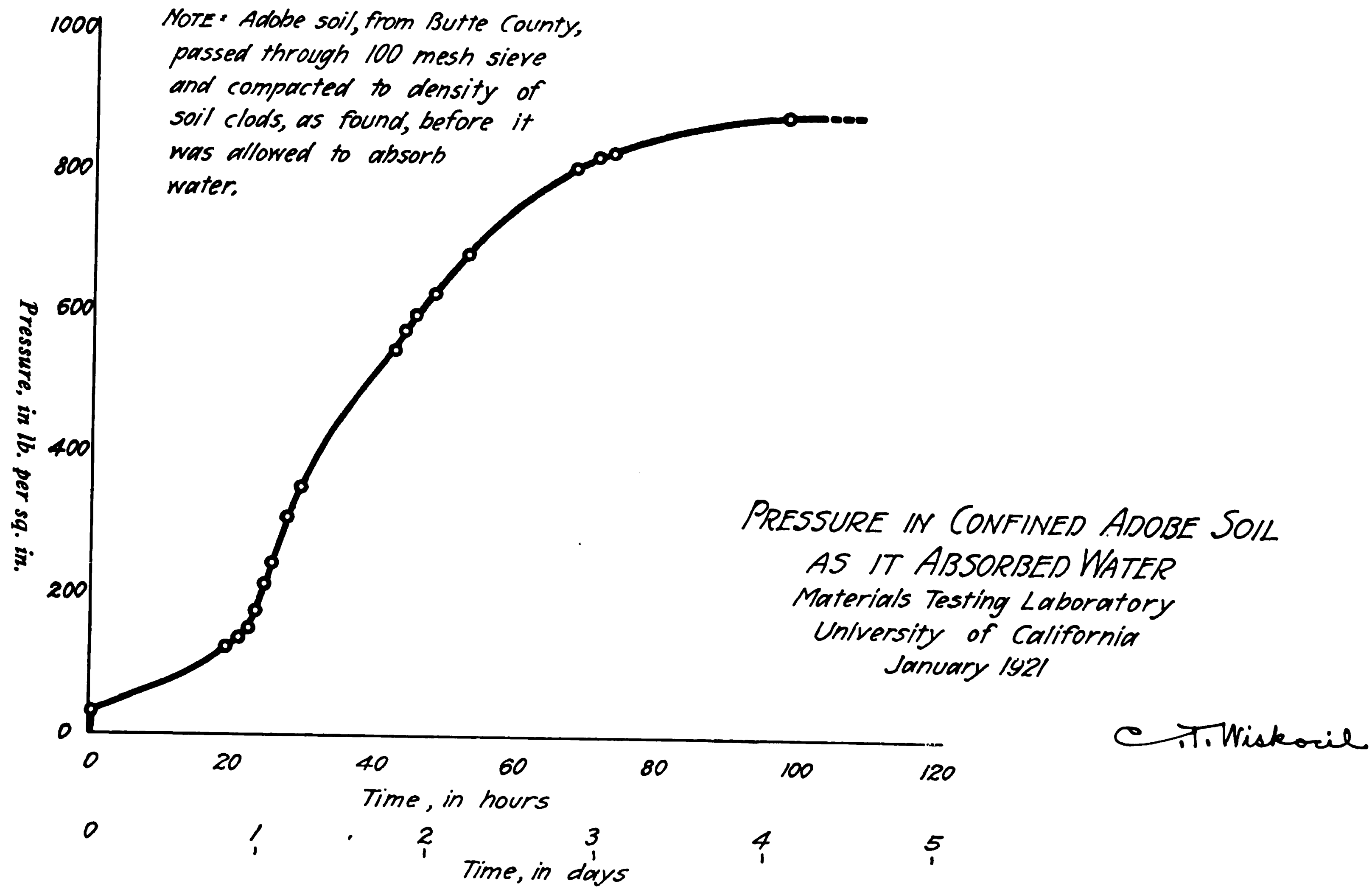
Plate XII



EFFECT OF SAND
ON MOISTURE-VOLUME RELATIONS
Butte County Adobe Soil
Materials Testing Laboratory
University of California
January 1921

C. T. Wiskocil

Plate XIII


NOTE: Adobe soil, from Butte County, passed through 100 mesh sieve and compacted to density of soil clods, as found, before it was allowed to absorb water.
Pressure, in lb. per sq. in.
1000
800
600
400
200
0
0
20
40
60
80
100
120
Time, in hours
0
1
2
3
4
5
Time, in days
PRESSURE IN CONFINED ADOBE SOIL
AS IT ABSORBED WATER
Materials Testing Laboratory
University of California
January 1921
C. T. Wiskocil

Volume Changes

In order to compare the experimental data they were all reduced to expansions based on oven-dry volumes.

From the results of the linear-shrinkage tests it was possible to secure data with which to plot moisture-volume curves. The volume changes were computed from the decrease in length of test specimens on the assumption that the soil contracted equally in all directions This assumption was apparently satisfactory because the changes in volumes determined from the tests in which the volumes were directly measured are on the volume curves computed from the linear-shrinkage tests. Shown thus -◇- on Plates III to IX.

The actual expansion obtained in the porous thimble test was very interesting in that it showed that expansions computed from shrinkage tests are comparable with actual expansions. See Plate VIII.

Additions of lime and sand did not seem to affect the volume changes, that is the total difference in volumes, but they did seem to decrease the rate of expansion for small amounts of moisture. See Plates X, XI, XII.

The lime and sand specimens were very brittle whereas those of the natural soil had considerable toughness.

The lime specimens showed much more cracking, breaking up into more pieces, than those of the natural soil.

Force in Confined Adobe Soil

The absorption of water by confined adobe soil caused a pressure of 880 lbs. per sq. in. or about 63 tons per sq. ft.

The specimen had absorbed about 12% water during the test which lasted over four days. During this time the specimen of soil was under a one-foot head of water.

Figure 7. Sand content of adobe soils (material retained on a 200-mesh sieve). The two jars at the left show the size of the original sample of soil.

Moisture Content

The moisture content for the various soils in air-dry condition, whether lumps or average material (small lumps and dust) was taken, and was about 6%. This does not include soil No. 9 from Tulare County which had over 50% sand and would naturally have a lower moisture content.

Sieve Analyses

No attempt was made to determine the grain size of the soil passing the 200-mesh sieve. Only that retained on this sieve was rescreened. According to this division, soils 2, 5, 11 and 13 were the finest while 30% or more of soils 9, 10, and 12 was retained on the 200-mesh sieve. It could be said that these latter soils contained more than 30% sand.

Specific Weights

Average adobe soil weighed about 87 lbs. per cu. ft. This is for loose air-dry soil with no large lumps and only slightly jarred so as to completely fill the measuring box.

The soil in the lumps weighs about 121 lbs. per cu. ft. average with a maximum of 133 lbs. per cu. ft.

It is interesting to note that it required a pressure of 430 tons per square foot to compact the dry loose adobe soil to the density of the natural lumps.

Strength

The average tensile strength of four air-dry specimens taken at random was 180 lbs. per sq. in. The maximum was 270 lbs. per sq. in.

Only one compression test was made. It was an air-dry specimen made from a mixture of several soils. Its maximum strength was 2,500 lbs. per sq. in.

SUMMARY OF RESULTS

1. Volume changes were satisfactorily computed from experimental data on linear-shrinkage tests.
2. The soils examined showed decided variation in grain size.
3. Air-dry adobe soils contained about 6% water.
4. High pressure was exerted by confined adobe soil when it absorbed water.
5. Confined adobe soil absorbed a relatively small amount of water.
6. Sand added to adobe soil did not produce a marked decrease in its volume changes.
7. An addition of 5% lime to adobe soil showed decided decrease in its volume changes when the moisture content was below 30%.
8. Lime added to adobe soil made it very brittle and caused it to break into smaller pieces than the natural soil.
9. Adobe soils increased about 1½% in volume from oven to air-dry conditions.
10. From air-dry to a stiff mud, a condition not easily defined, the adobe soils examined increased about 37% in volume. The range was 16 to 51%. Table V.
11. With adobe mud thin enough to be poured the increase in volume from air-dry condition was about 67%. The range was from 28 to 93%. Table V.
12. The soils examined required different amounts of water to bring them to the same degree of plasticity.
13. A pressure of about 864,000 lbs. per sq. ft. was required to compact loose, air-dry adobe soil to the density of the natural lumps.
14. The maximum tensile strength of a sample of adobe soil was 270 lbs. per sq. in.
15. The maximum compressive strength of a sample of air-dry adobe soil was 2,500 lbs. per sq. in.

No. 1 October 22, 1920

APPENDIX A, PRELIMINARY REPORTS

ADOBE SOIL TESTS

Information of greatest immediate value would be obtained from tests similar to those now being made by the Bureau of Public Roads.

1. Slabs of concrete 7 ft. by 7 ft. say 6 in. thick.
2. Placed directly on subgrade of adobe soil in various conditions of moisture content and adulteration.
3. Similar slabs on good gravel or crushed rock subgrade.
4. Test under static load, determine deflection of slab and fiber stresses at various positions in the slab during the progress of the test.

Supplementing these tests the bearing power of adobe soil and other characteristic California subgrade materials could be determined as follows:

1. Pulverize sample, place in container about 14 inches in diameter and 8 inches deep. Let the soil absorb water from below, then dry the sample in air. Repeat this process until a constant volume is secured. (This method is far more satisfactory than mechanical tamping or other manipulation to secure uniform compactness of sample.)
2. Fill space between test sample and container with Plaster of Paris and place in testing machine.
3. Apply test load through flat-bottomed circular plunger (10 square inches in cross-sectional area) to center of upper surface of sample.
4. Get data for load-deflection curve.

I think that it would be impossible to prepare samples of adobe soil in this manner. The most practical and satisfactory method could only be determined by actual experiment but the test itself could be made as outlined.

The adobe soil could be adulterated in any manner and the effect of such treatment on its bearing power readily determined.

This is essentially the method used by the Bureau of Public Roads. I got the information verbally from a remote source, and it may not be correct, but there is no doubt that this method would be only our starting point if we attempted such tests. Adobe soil is in a class by itself and demands individual methods.

If possible the grain size should be determined, see A. S. C. E. proceedings August, 1920, page 913. Change in volume under various moisture conditions should also be noted.

(Signed) C. T. WISKOCIL.

No. 2 October 25, 1920.

TESTS ON ADOBE SOIL

1. Contraction and Expansion

1a Adobe in natural condition (as found).

- 1a1 Prepare samples, made of adobe soil paste, as large as can be conveniently manipulated.
- 1a2 Dry sample at room temperature for seven days.
- 1a3 Determine volume of dried adobe soil.
- 1a4 Compute percentages of contraction (percentage reduction in volume on basis of 1a1).
- 1a5 Resoak sample.
- 1a6 When sample has absorbed all the water it will, determine its volume.
- 1a7 Compute expansion as percentage increase in volume on basis of volume in 1a3.

1b Adobe soil mixed with foreign materials, such as sand, gravel, rock, or lime. (Same procedure as in 1a.)

2. Bearing Power

2a Adobe soil in natural condition (as found).

2a1 Pulverize sample, place in container about 14 inches in diameter and 8 inches deep. Let the soil absorb water from below, then dry the sample in air. Repeat this process until a constant volume is secured. This method is far more satisfactory than mechanical tamping or other manipulation to secure uniform compactness of sample.

2a2 Fill space between test sample and container with Plaster of Paris and place in testing machine.

2a3 Apply test load through flat-bottomed circular plunger (10 square inches in cross sectional area) to center of upper surface of sample.

2a4 Get data for load-deformation curve.

3. Strength of Concrete Slabs on Adobe Soil Subgrade

3a1 Prepare slabs of cement concrete 7 feet by 7 feet by 6 inches.

3a2 Place cured slabs on subgrade of adobe soil.

3a21 Natural adobe soil—vary moisture.

3a22 Adobe soil mixed with foreign materials vary moisture as in 3a21.

3a3 Test slabs under static load, determine deflection and fiber stresses at various points in the slab during progress of test.

4. Grain Size

4a See A. S. C. E. Proceedings, August, 1920, page 913.

(Signed) C. T. WISKOCIL.

No. 3 December 8, 1920.

Dear Professor Derleth:

At our conference during which the letter of December 1 was written to Messrs. Lippincott and Brunnier you instructed me to prepare a statement of what we have been doing in the laboratory on adobe soil.

The first revised program of October 25, also contained in your letter of October 29 to Messrs. Lippincott and Brunnier, has been adhered to insofar as possible. The results however while in a sense negative will be of great value in showing us what not to do.

The laboratory work I am about to describe was done during the month of November. We attempted to follow the procedure recommended by Professor Shaw to the engineers of the Bureau of Public Roads working under Dr. Hewes. The actual work for this Bureau was done by Miss Edith Phillips, working in Professor Shaw's laboratory in Hilgard Hall. The work they were particularly interested in was the amount of shrinkage and expansion in adobe soil. This work was carried on as follows:

The sample of soil was crushed by hand and then pulverized. A small quantity of this pulverized soil was mixed with water until it attained the consistency of rich cream. The mud in this condition was poured into small cups 2 inches in diameter and ½-inch deep, weighed and set aside to dry. After air-drying to a constant weight, the volume of the specimen was determined by micrometer measurements. In most cases a solid single piece of soil was obtained. Where the soil in drying cracked or adhered to the container the specimen was rejected. This method of obtaining volumes was later abandoned because of its known inaccuracy. The results as finally recorded were obtained by immersing the dry specimens in mercury. While this method is no doubt more accurate than the one first used it nevertheless was quite cumbersome and could be improved upon.

Up to this time the results to my knowledge have not been computed and tabulated; but Miss B. F. Monroe, Professor Shaw's laboratory assistant, thinks that the average shrinkage was about 20% in volume, on the basis of the original mud paste.

With this information in mind our first idea was to obtain a larger specimen than that used by the Bureau of Public Roads so as to reduce the experimental errors in determining the volumes. We therefore decided to use a cylindric shape. We adopted two sizes as follows: (a) 2.4 inches diameter by 4½ inches long; (b) 1.3 inches diameter by 4½ inches long. (These molds are in the background of Figure 8.) Soil No. 12, from Ventura County, was crushed and passed through a 100-mesh sieve. It was then mixed with a known amount of water to such a consistency that it could be poured from a container into a mold. Instead of air-drying these samples we attempted to accelerate this part of the test by more rapid drying, but without success. The specimens cracked and checked so that they were of no further use. Even approximate determinations of shrinkage could not be made.

Another source of inaccuracy was the condition of the mud paste; but to be sure that our molds were of the proper size we tried a smaller set 1.3 inches in diameter and 2.7 inches long. (One of these molds is shown in Figure 8.) These molds were paraffined and placed on greased plates. The mud paste was poured into the molds and they were set aside to dry. After a week's time only the upper portion had dried. The lower part still filled the mold and was in its original wet condition. One of these smaller molds is in the background of Figure 8. It became obvious, therefore, that the entire surface of the specimen must be subjected to air instead of just the top as was the case in any of the molds used. In doing this it is clear that the mud must be of thicker consistency. Just yesterday we tried mixing the pulverized adobe soil with small quantities of water, thoroughly kneading the mixture with additional water until it had a uniform texture. The consistency was about that of modeling clay and very easily handled.

We now propose to make up cylindric specimens of adobe soil of the consistency mentioned, remove the mold immediately and in that way we will be able to expose a large surface to dry and thus overcome one of the previous obstacles. The procedure will be as follows:

1. Weigh out pulverized adobe soil, add water until the proper consistency is secured. This will require very thorough kneading. Record the amount of water used and calculate the percentage of moisture on the basis of dry material.
2. Compact the adobe paste into the oiled mold.
3. Remove specimen from mold. If it has any air bubbles or other holes visible, discard. If it appears to be a solid homogeneous mass, weigh and immerse in kerosene to determine its volume.
4. Set aside to dry under room conditions.
5. To check the percentage moisture in the material molded into specimens make a moisture determination in the usual way by drying to a constant weight at 100 degrees Centigrade.
6. After the specimen has dried one week in air place in a cold oven which will gradually be brought to a maximum temperature of 70 degrees C. After they have dried to a constant weight raise the temperature to 110 degrees C.
7. Weigh the dried specimens.
8. Immerse the specimen in kerosene until it will absorb no more. Then determine the volume as was previously done with the wet specimen.
9. Compute percentage reduction in volume on the basis of dry volume.

We think, at this time, that this procedure will give us uniform, comparable results that will be of value. We realize that we are not duplicating field conditions in that the mud may be wetter than we use it and field drying is not 100 degrees C. The conditions to be used are, however, consistent with general laboratory practice and when obtained under known conditions, results can be modified according to the judgment of the person using them. We propose to mold specimens from each sample obtained. We will choose one sample which

represents the average condition and to it add sand and other materials as outlined in 1b in letter of October 29, previously referred to.

We have attempted to use compact lumps of adobe as obtained from field samples, but here we have also been unsuccessful. All the material so far examined contains pebbles or small hard particles which strike against the tool used in dressing the specimen and either tear large gashes or break it so that it can not be used. From conferences and searches in the library, we conclude at this time that it is impossible to secure valuable data on expansion. We will try out any new ideas if obtained, but we will concentrate on the program outlined which we expect will give reliable data on shrinkage.

Very truly yours,
(Signed) C. T. WISKOCIL.

No. 4 December 25, 1920.

ADOBE SOIL

1. Percentage moisture (air-dry, in laboratory about three months).
   1a Lumps.
      1a1 Medium size, about 5 cu. in.
      1a2 Large size, about 200 cu. in.
   1b Loose material.
      1b1 Average soil, maximum size lump 1 cu. in.
      1b2 Material passing 100-mesh sieve.
2. Shrinkage, paste made with different percentages water.
   2a Made by hand from soil passing 100-mesh sieve.
      2a1 Air-dry.
      2a2 Oven dry.
   2b Made by hand from average material.
      2b1 Air-dry.
      2b2 Oven-dry.
   2c As affected by additions of sand.
      2c1 10% sand by weight.
      2c2 20% sand.
      2c3 40% sand.
   2d As affected by additions of lime.
      2d1 1% lime.
      2d2 5% lime.
3. Expansion, air-dry to saturated condition (in porous mold).
   3a Specimen cut from lump.
   3b Specimen compacted from dust.
4. Force of expansion, produced by absorption of water by confined mass of adobe soil. Adobe passing 100-mesh sieve.
5. Specific weights (air-dry).
   5a Lumps in lbs. per cu. ft.
   5b Average material slightly tamped.
   5c Material passing 100-mesh sieve.
6. Linear contraction.
   6a Specimens made from material passing 100-mesh sieve.
   6b Specimens made from soil as received.
7. Sieve anlyses.

(Signed) C. T. WISKOCIL.

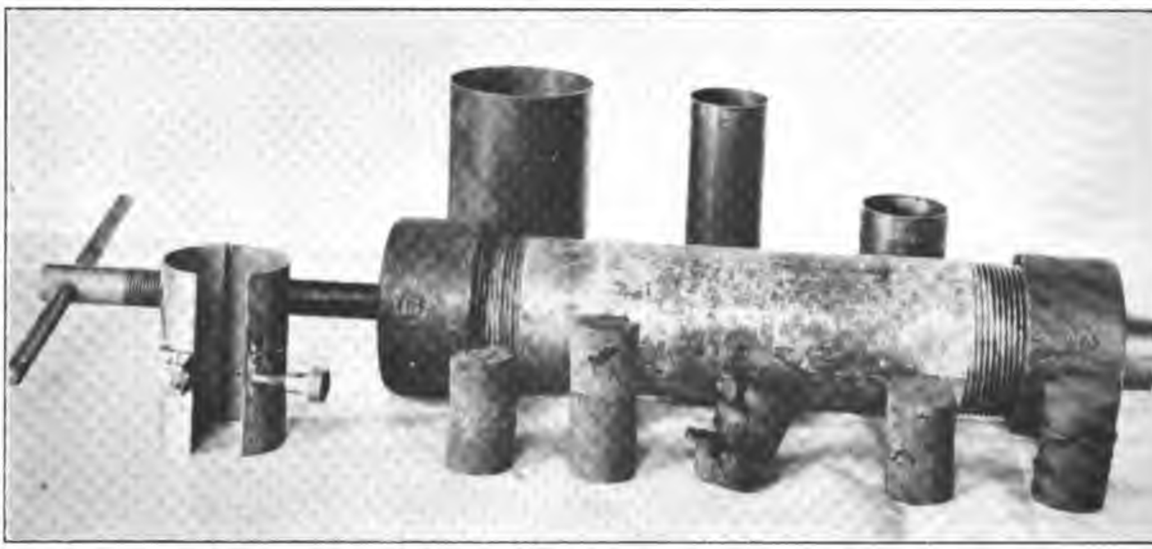


Figure 8. Apparatus and various molds specially made, but found to be unsatisfactory; also a few specimens, some of which are defective.

December 23, 1920.

Mr. J. B. Lippincott, Consulting Engineer,
Automobile Club of Southern California.
Mr. H. J. Brunnier, Chairman, Highway Committee,
California State Automobile Association.

Gentlemen:

I submit our report on 20 experimental concrete slabs, eight plain, five reinforced with mesh and seven with bars.

The object of these tests was to determine the relative bending efficiency of reinforcement versus increased concrete thickness.

The table on page 8 gives a summary of the slabs tested and indicates their carrying capacity at three stages during test to rupture,

a—at the proportional limit.
b—at the first crack.
c—at the maximum load sustained.

Our report not only records the loads carried, but has made careful inquiry into the behavior of the slabs under deflection. The particulars are given in the deflection load curves, pp. 16-23.

CONCLUSIONS

1. The large scale load deflection curves show that the proportional limit is the most reliable basis for the comparison of slab strengths.

2. At their respective proportional limits, the reinforced slabs are not as strong as plain slabs one inch thicker.

3 At the proportional limit the reinforced slabs 4 inches and 5 inches thick had less than 50% of the strength of plain slabs 6 inches and 7 inches thick, respectively; that is, the 2 inches of extra concrete thickness practically doubled the strength of the plain slabs.

4. The reinforcement was placed 1½ inches from the bottom of each slab in its tested position. Had the reinforcement been placed at the center of the slab's depth, the comparative results would have been still less favorable to the reinforced slabs.

5. If the plain and reinforced concrete slabs are compared for load-carrying capacity, either at the first crack or at the maximum load sustained, the plain slabs still have an ample margin of increased strength over reinforced slabs 2 inches less in thickness.

C. DERLETH, Jr.

UNIVERSITY OF CALIFORNIA

CONCRETE-SLAB TESTS

December, 1920

Made for
AUTOMOBILE CLUB OF SOUTHERN CALIFORNIA
CALIFORNIA STATE AUTOMOBILE ASSOCIATION

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December 21, 1920.

Professor C. Derleth, Jr.,
Dean College of Civil Engineering,
Campus.

Dear Professor Derleth:

This is my report on the CONCRETE-SLAB TESTS made for the California State Automobile Association and the Automobile Club of Southern California.

Your letter of September 2, 1920, is my authorization for making these tests.

Respectfully submitted,

C. T. WISKOCIL,

Associate Professor of Civil Engineering in Charge of Materials Testing Laboratory.

UNIVERSITY OF CALIFORNIA CONCRETE-SLAB TESTS

The tests described in this report were made to investigate the relative strengths of reinforced concrete slabs and plain concrete slabs of greater thickness. The following summary gives the scope of the investigation:

Number of Slabs Tested	Thickness of Slab in Inches	Type of Reinforcement
3	5	None
2	6	None
3	7	None
2	4	One Bar
3	5	One Bar
2	5	Two Bars
2	4	Wire Mesh
3	5	Wire Mesh

All slabs 18 inches by 45 inches, tested on a 42-inch span with third-point loading.

Materials Used

Aggregates: The fine aggregate was Napa Gravel weighing 103 lbs. per cu. ft. The coarse aggregate was 1½-inch crushed stone weighing 93 lbs. per cu. ft. The sieve analysis gives the gradation.

Sieve Size	Percentage Retained on Given Sieve	
	Napa Gravel	Crushed Stone
100 mesh	98	100
48 mesh	95	100
28 mesh	88	100
14 mesh	77	100
8 mesh	57	100
4 mesh	32	100
⅜ inch	10	100
¾ inch	0	78
1½ inch	0	0

The fineness modulus of the Napa gravel was 4.57 while that of the crushed stone was 7.78.

Cement: Santa Cruz Portland cement, furnished by the Santa Cruz Portland Cement Company of San Francisco, was used for all tests.

Specific gravity		3.09
Fineness, rejected by 200 mesh sieve		8.4%
Time of set	Initial	5 h., 10 min.
	Final	7 hr., 00 min.
Constancy of Volume	Air	Satisfactory
	Steam	Satisfactory
	Water	Satisfactory
Normal consistency		22% water required
Tensile strength		1:3 mortar, in lb. per sq. in.
	7 days	341
	28 days	453
Compressive strength		1:3 mortar, in lb. per sq. in.
	7 days	2,550
	28 days	3,620

Reinforcement Steel: All furnished by the United States Steel Products Company of San Francisco.

Bars: Normal size 3/8-inch square corrugated

Dimensions, inches	.378 by .378 (area .143 sq. in.)
Yield point, lb. per sq. in.	40,000
Maximum strength, lb. per sq. in.	60,600
Percentage elongation	26.6
Percentage reduction in area	63.0

Wire Mesh: American Steel and Wire Company's Style 093 triangle mesh. Longitudinal wires spaced 4 inches apart.

Longitudinal wires		Transverse wires
Diameter, inches	.192	.079
Area, sq. in.	.029	.0049
Yield point, lb. per sq. in.	75,800	81,500
Maximum strength, lb. per sq. in.	83,500	88,700
Percentage elongation	9.3	4.0
Percentage reduction in area	58.5	...

Water: Berkeley tap water was used. It is a medium-hard water supplied by the East Bay Water Company. It is a mixture of well and surface waters.

Concrete:

Proportions: The concrete was proportioned by volume, one part cement to five parts aggregate (1:5). The materials for each batch were weighed out, the weights of unit volumes having been previously determined except for the cement which was taken as 94 lbs. per cu. ft., the usual procedure. The aggregates themselves were proportioned by weight; 69% Napa gravel to 31% crushed stone. The sieve analysis was used in deciding upon these proportions. See DESIGN OF CONCRETE MIXTURES by Duff A. Abrams, Bulletin No. 1, Lewis Institute, Chicago, Illinois. One cubic foot of the aggregates proportioned as indicated weighed 120 lbs. The Napa gravel had sufficient fine material to produce an easy-working concrete without the use of too much water.

This concrete is the practical equivalent of a 1:2:4 mix in which the sand is material smaller than the openings in a No. 4 sieve and the large aggregate is material retained on this sieve.

Mixing: The concrete for the first group of slabs A-1, C-1, E-1 and G-1 was mixed in a 3 cu. ft. Smith mixer. After the materials had been put into the mixer it was run for one minute; then the entire charge was dumped out. It was impossible to get all the concrete out of the mixer. This would not have been the case with a second batch, but since we were using only a single batch and the material in the mixer was mostly fine material it was decided to mix the other batches by hand.

In the hand mixing the procedure for each batch was the same. The aggregates were spread on a concrete floor and turned twice. The cement was then added. After two more turnings the water was added and the mixing continued. Three turnings with the water or a total of seven was needed to get a uniform mixture.

It is interesting to note that little difference was found between the strengths of the first group of slabs made of machine-mixed concrete and the other slabs (identical in every other way) made from hand-mixed concrete. There are many other factors other than the kind and time of mixing that affect the strength of concrete.

Amount of Water. The water required was about 7% by weight of the total dry materials used.

Consistency. The cone test was used to determine the consistency. All the concrete used had a slump between ½ and 1-inch. It was not practical to work to a closer limit on such large batches.

Strength. The average compressive strength of all concrete (12 specimens representing 5 batches) was 1,080 lbs. per sq. in. at the proportional limit—the load at which the deformation-load curves deviate from a straight line—and 2,370 lbs. per sq. in. at the maximum.

Elasticity. The average modulus of elasticity for all concrete used was 2,160,000 lbs. per sq. in.

Test Specimens:

Cylinders. Cylindric test specimens, 6 inches by 12 inches, were molded with the concrete used in making each group of slabs. These specimens were stored and tested with the slabs.

Slabs. Dimensions. The slabs were 18 inches wide, 45 inches long and 4, 5, 6 and 7 inches thick as indicated.

Molding. Four wooden forms were used. The concrete was tamped into forms in layers of about 3 inches in thickness and struck off with a template to get the desired thickness of slabs. No roller was used to remove the excess water.

Age. All slabs were tested 28 days after being molded.

Storage. The specimens were removed from the forms and placed in damp sand two days after being molded. The sand was wet once a day. On the 27th day the slabs were taken from the sand and allowed to dry in air until tested.

Reinforcement. The steel ratio $p = A_S \div bd$, where As is the cross section area of steel in square inches, b is the breadth of the slab in inches and d is the effective depth in inches. Effective depth is the distance from the top of the slab to the center of gravity of the reinforcing steel.

Steel Ratio for Wire Mesh Slabs:

A_S from catalogue .093x18/12=0.140 sq. in.

A_S from actual dimensions of bars which are the same as given in the catalogue is 5x.02895=0.145 sq. in. This neglects the transverse wires.

For the 4-inch slabs p=.0033.
For the 5-inch slabs p=.0023.

Steel Ratio for One-Bar Slabs:

A_S=.143 sq. in. by actual measurement.

For the 4-inch slabs p=.0028.
For the 5-inch slabs p=.0021.

Steel Ratio for Two-Bar Slabs:

A_S=0.286 sq. in.

For 5-inch slab p=.0045.

Testing:

Cylinders. The cylinders were crushed on a 100,000-lb. Riehle Testing Machine. The apparatus used (shown in Figure 7) indicated the average of the deformation taken on two sides of the specimen. The load was applied continuously and simultaneous observations of load and corresponding deformation were recorded.

Slabs. The slabs were too wide to be placed directly under the head of our 200,000-lb. Olsen Testing Machine. They were, therefore, set up on the table extension and the load was transmitted from the movable head of the machine to the slabs by an auxiliary beam. One end of this beam is shown in Figure 1. The other end, an equal distance from the center of the machine, transmits its portion of the load directly to the weighing table.

The manner of loading and supports of the slab itself are shown in Figure 1. The pieces on the third-points were 2-inch by 4-inch steel bars. The span was 42 inches center to center of end rollers.

The actual bearing surfaces on the slabs were prepared with plaster of paris so that uniform load was applied across the entire specimen. The deflection was measured at the center by an Ames dial reading to thousandths of an inch. The bar carrying the dial was attached to the slab at the neutral surface directly over the supports. This apparatus is not shown in Figure 1.

The specimen after being weighed was placed in the machine and the apparatus adjusted. Simultaneous readings of load and corresponding deflection were observed and recorded. The load was applied continuously until the slab failed.

The testing machine was calibrated with standard weights so that the actual load applied to the slab was accurately known. The calibrating levers were placed in the position occupied by the slab and the load on the scale-beam read as it was during actual testing.

RESULTS

The test results have been tabulated and are also shown graphically. The principal tables and curves follow in the order given in the table of contents.

SUMMARY

U. OF C. CONCRETE-SLAB TESTS

Kind of Reinforcement	Nominal Thickness in Inches	Number of Slabs Tested	Load on Slab in Pounds		
			At Proportional Limit	At First Crack	At Maximum
None	5	3	1990	3650	3650
None	6	2	4660	5860	5860
None	7	3	6590	8240	8240
Mesh	4	2	1740	2700	3870
Mesh	5	3	2800	4370	6820
One bar	4	2	1810	2970	3075
One bar	5	3	3250	4350	4580
Two bars	5	2	2870	4300	8560

NOTE: The load was applied at third-points.

The load at first crack taken from curves at center deflection of 0.02 inches. This is the deflection at which the 4-inch slabs cracked and is arbitrarily taken as the deflection at first crack for all slabs. The load obtained in this way is used only to compare the various slabs.

The wire mesh used was furnished by the American Steel and Wire Co. It is their style No. 093 Triangle Mesh, weighing 45 lbs. per 100 sq. ft.

SLAB-TEST DATA

U. OF C. CONCRETE-SLAB TESTS

Mark	Group No.	Thickness, in.	Width inches	Weight lbs.	Modulus of Rupture lb. per sq. in.	Load on Slab in lbs.		Effective Depth	Reinforcement	Steel Ratio
						at Proportional Limit	At Maximum			
A-1	1	5.01	18.10	352	306	1950	3310	....	None	....
A-2	4	4.91	18.20	332	338	2070	3530	....	None	....
A-3	5	5.03	18.10	344	377	1940	4110	....	None	....
B-1	2	5.96	18.10	413	374	4400	5720	....	None	....
B-2	3	5.94	18.17	407	392	4920	5990	....	None	....
C-1	1	7.00	18.10	485	378	6750	7990	....	None	....
C-2	2	7.11	18.07	492	419	7040	9110	....	None	....
C-3	3	6.93	18.13	478	365	5990	7570	....	None	....
D-1	4	4.06	18.15	282	....	1540	4110	2.41	Mesh	.0033
D-2	5	3.97	18.11	273	....	1940	3630	2.40	Mesh	.0033
E-1	1	5.05	18.00	352	....	2520	7370	3.55	Mesh	.0023
E-2	2	5.10	18.10	353	....	2280	6940	3.35	Mesh	.0024
E-3	3	5.05	18.10	350	....	3600	6140	3.49	Mesh	.0023
F-1	4	4.08	18.10	278	....	1810	3050	2.88	1 bar	.0027
F-2	5	3.96	18.10	276	....	1810	3100	2.71	1 bar	.0029
G-1	1	4.87	18.15	344	....	2790	4210	3.77	1 bar	.0021
G-2	2	4.99	18.05	347	....	3870	4920	3.49	1 bar	.0023
G-3	3	4.98	18.12	344	....	3070	4610	3.98	1 bar	.0020
H-1	4	5.08	18.10	347	....	2470	8300	3.38	2 bars	.0047
H-2	5	5.08	18.05	348	....	3260	8820	3.58	2 bars	.0044

COMPARISON OF PLAIN AND REINFORCED CONCRETE SLABS
U. OF C. CONCRETE-SLAB TESTS

Slabs		Comparative Load Carrying Capacity in Percentage		
Thickness	Kind of Reinforcement	At Proportional Limit	At First Crack	At Maximum Load
7	None	100	100	100
5	None	30	44	44
5	Mesh	42	53	83
5	One bar	49	53	56
5	Two bars	44	52	104
6	None	100	100	100
4	Mesh	37	46	66
4	One bar	39	51	53
6	None	100	100	100
5	Mesh	60	75	116
5	One bar	70	74	78
5	Two bars	62	73	146
5	None	100	100	100
4	Mesh	87	74	106
4	One bar	91	81	84

SUMMARY COMPRESSIVE STRENGTH AND ELASTICITY OF CONCRETE
U. OF C. CONCRETE-SLAB TESTS

Group	Represents Concrete in Slabs	Strength at Proportional Limit, lbs. per sq. in.	Maximum Compressive Strength, lbs. per sq. in.	Modulus of Elasticity in lbs. per sq. in.
First	C-1, G-1 E-1, A-1	1200	2660	2,840,000
Second	C-2, G-2 E-2, B-1	1010	2700	2,140,000
Third	C-3, G-3 E-3, B-2	1170	2260	1,670,000
Fourth	A-2, D-1 F-1, H-1	850	2120	1,920,000
Fifth	A-3, D-2 F-2, H-2	1180	2400	2,570,000

NOTE: Strength at proportional limit is taken from curves as load at which deflection-load curve deviates from a straight line.

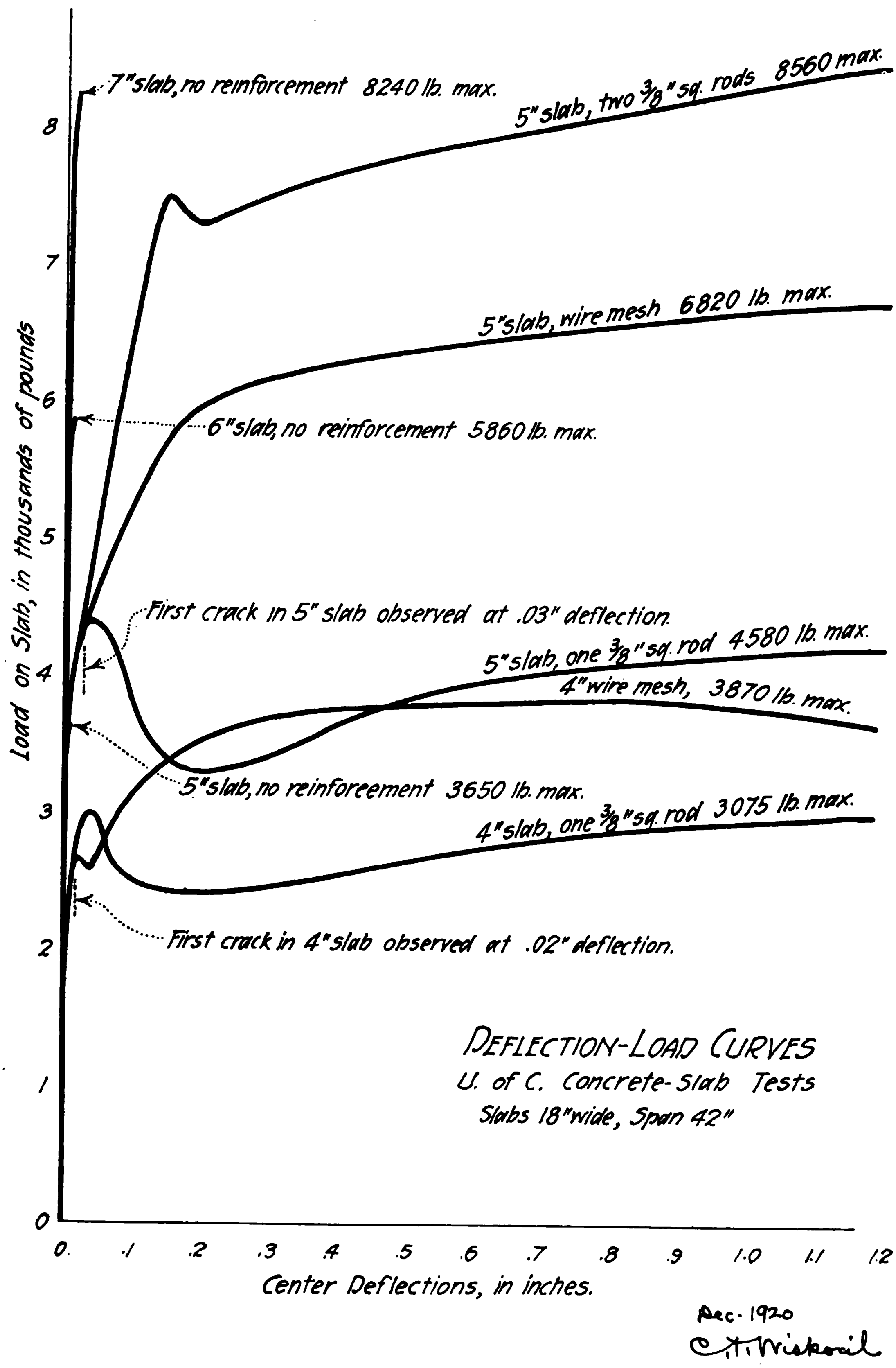
STRENGTH-TEST DATA
(6-inch by 12-inch cylinders)
U. OF C. CONCRETE-SLAB TESTS

Specimen Number	Weight, in lbs.	Diameter, in inches	Area, in sq. inches	Maximum Compressive Strength, lbs. per sq. in
1-A	30.4	6.17	29.9	2,660
2-A	30.5	6.16	29.8	2,770
2-B	30.5	5.16	29.8	2,640
3-A	30.4	6.17	29.9	2,170
3-B	30.3	6.19	30.1	2,310
3-C	30.6	6.18	30.0	2,300
4-A	29.5	6.15	28.7	2,050
4-B	29.5	6.10	29.2	2,170
4-C	29.5	6.13	29.5	2,140
5-A	30.6	6.10	29.2	2,420
5-B	31.0	6.15	29.7	2,410
5-C	31.4	6.17	29.9	2,400

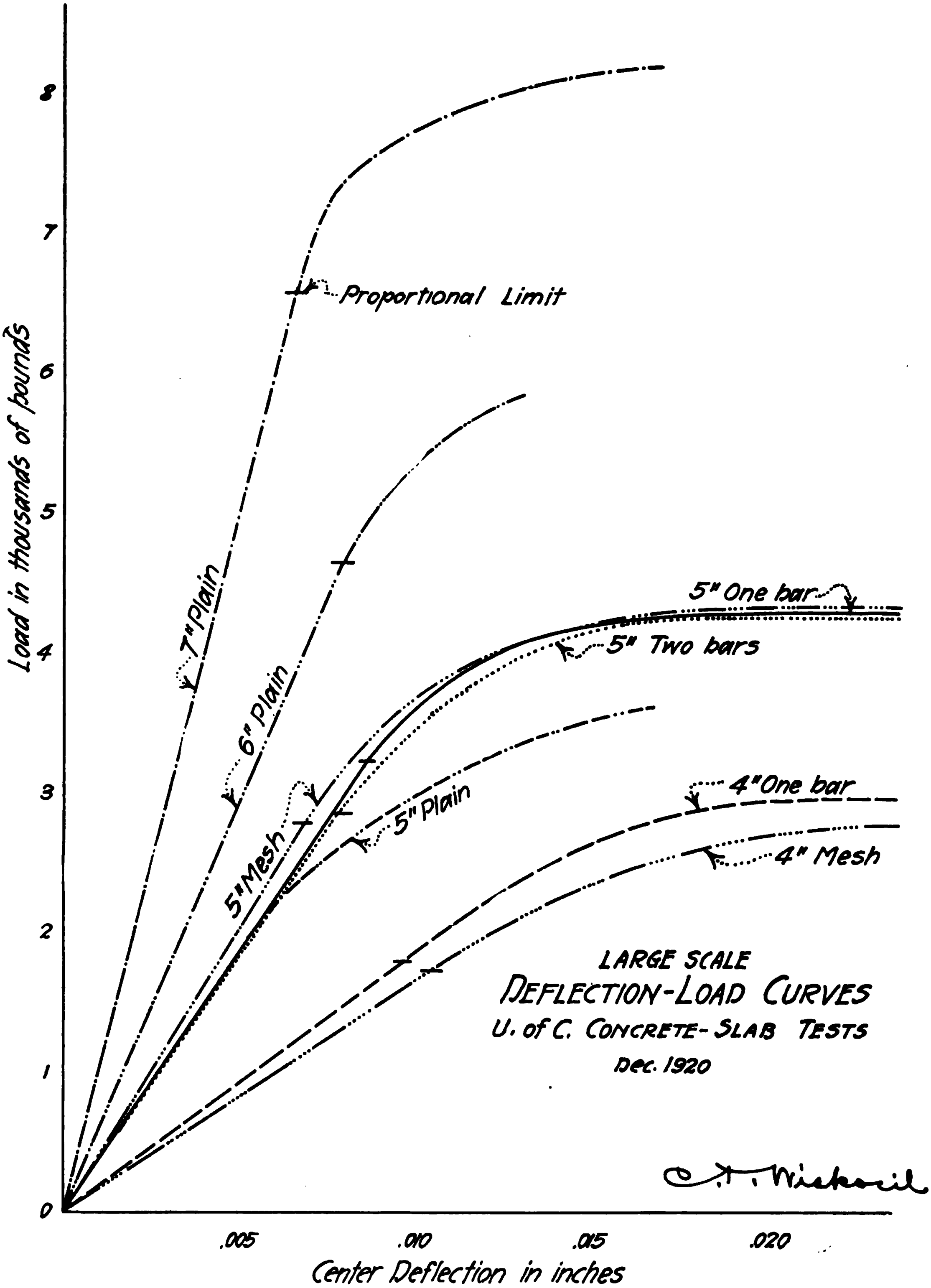
Age: All cylinders tested 28 days after being molded.

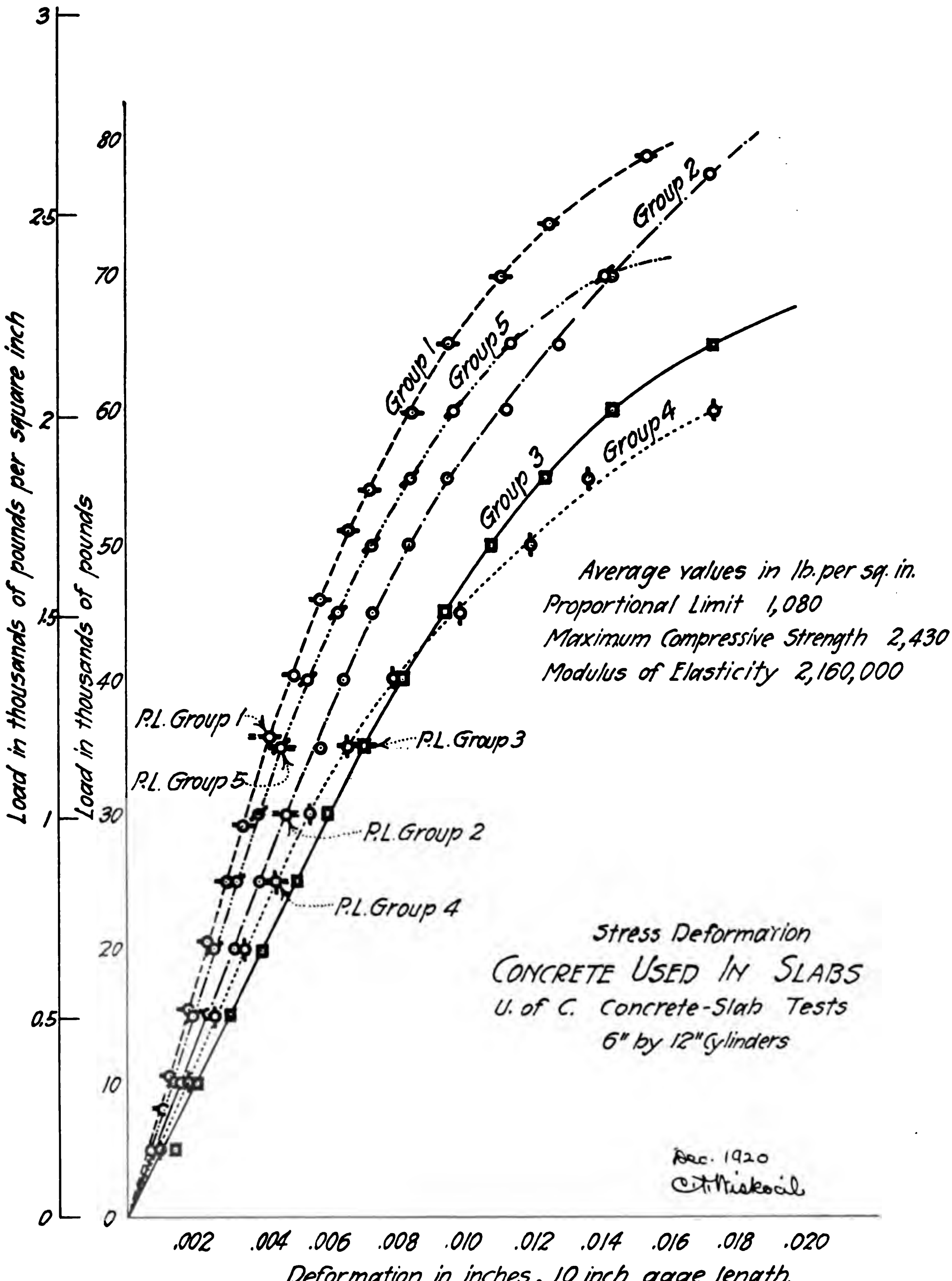
Storage: 2 days in mold, 25 days in damp sand, 1 day in air.

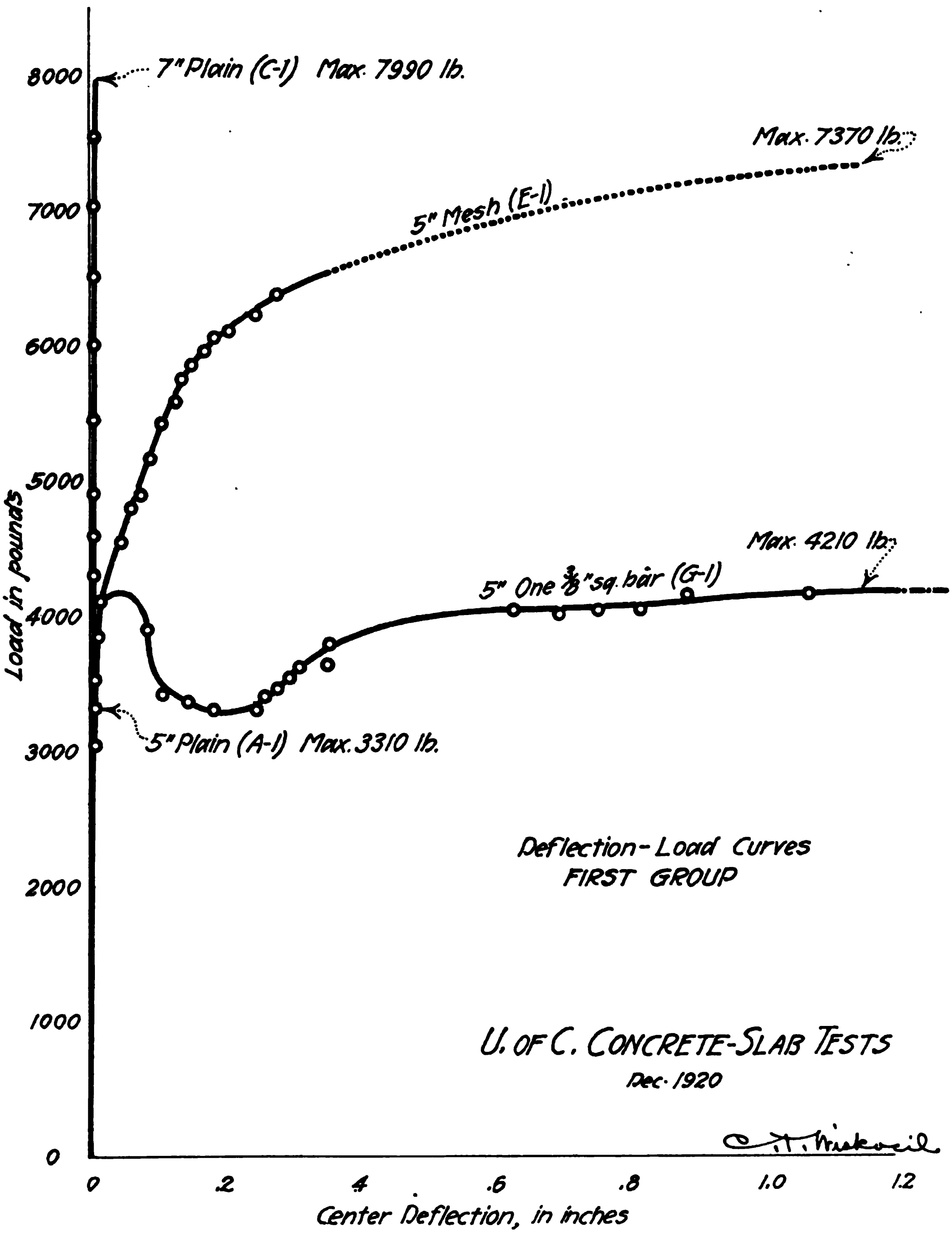
Height: 12 inches.



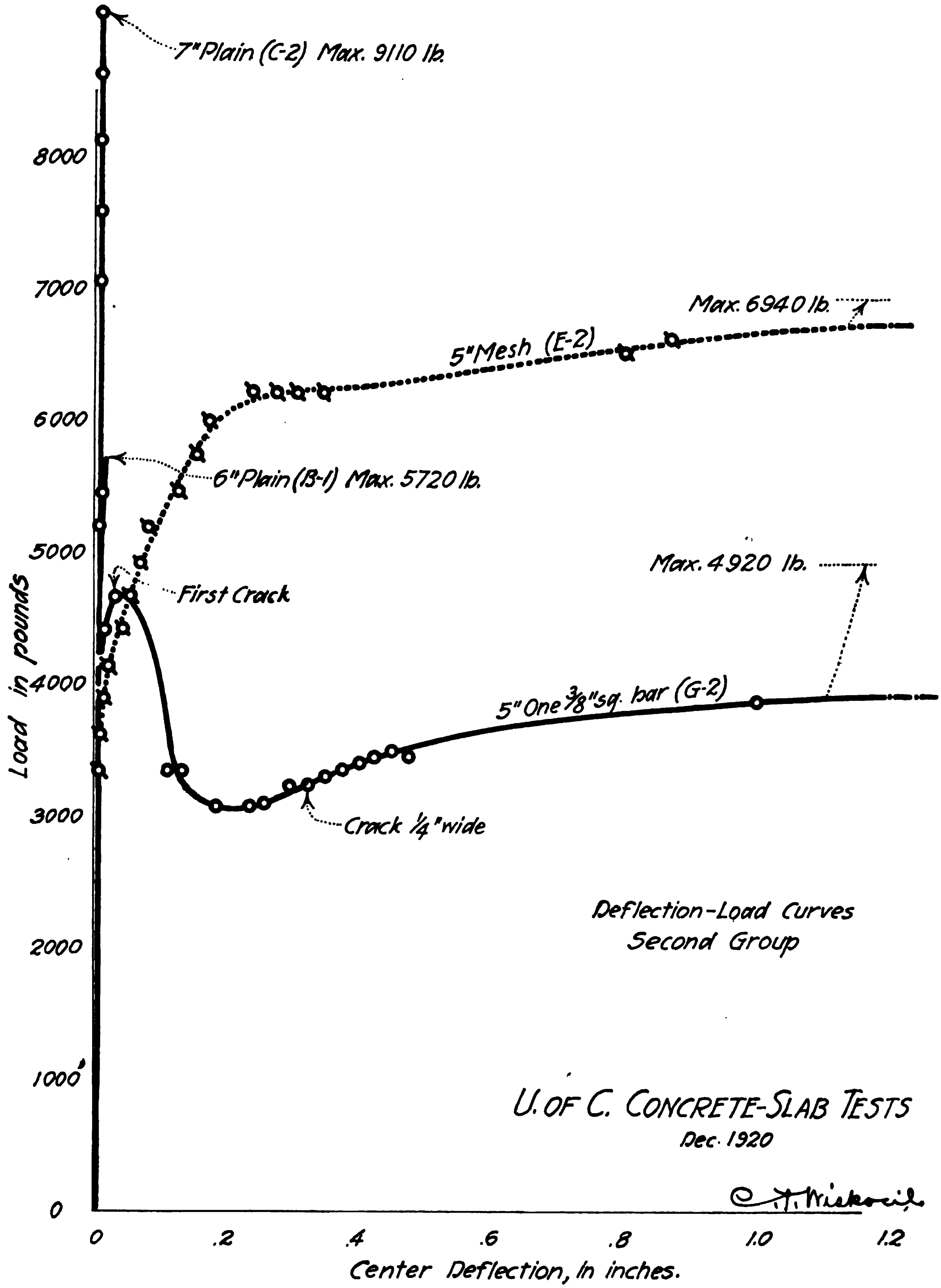
7"slab, no reinforcement 8240 lb. max.
5"slab, two 3/8"sq. rods 8560 max.
5"slab, wire mesh 6820 lb. max.
6"slab, no reinforcement 5860 lb. max.
First crack in 5" slab observed at .03" deflection.
5"slab, one 3/8"sq. rod 4580 lb. max.
4"wire mesh, 3870 lb. max.
5"slab, no reinforcement 3650 lb. max.
4"slab, one 3/8"sq. rod 3075 lb. max.
First crack in 4"slab observed at .02" deflection.
DEFLECTION-LOAD CURVES
U. of C. Concrete-Slab Tests
Slabs 18"wide, Span 42"
Load on Slab, in thousands of pounds
0
1
2
3
4
5
6
7
8
0.
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
Center Deflections, in inches.
Dec. 1920
C. A. Wiskocil

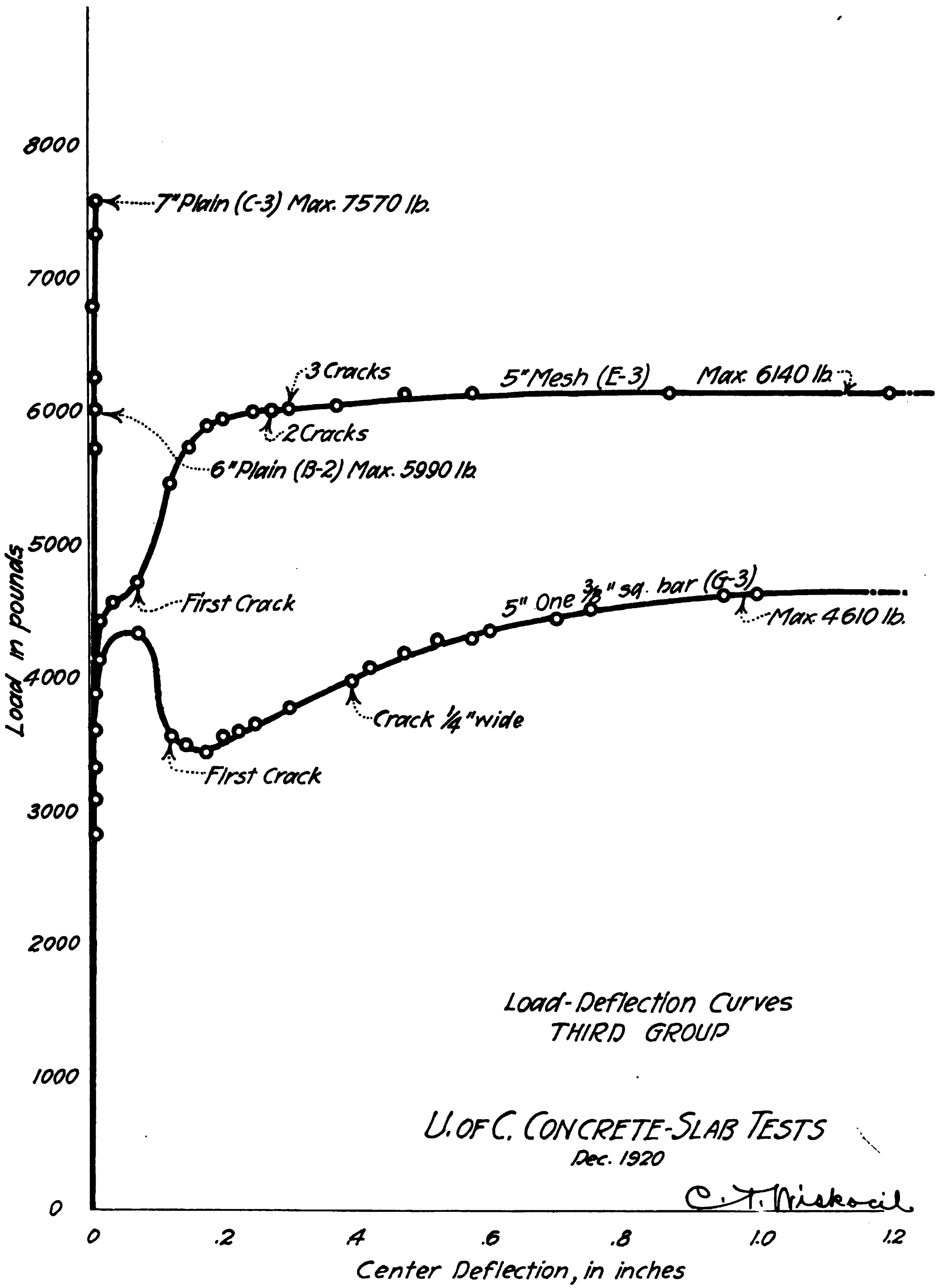

Load in thousands of pounds
0
1
2
3
4
5
6
7
8
.005
.010
.015
.020
Center Deflection in inches
Proportional Limit
7" Plain
6" Plain
5" One bar
5" Two bars
5" Mesh
5" Plain
4" One bar
4" Mesh
LARGE SCALE
DEFLECTION-LOAD CURVES
U. of C. CONCRETE-SLAB TESTS
Dec. 1920

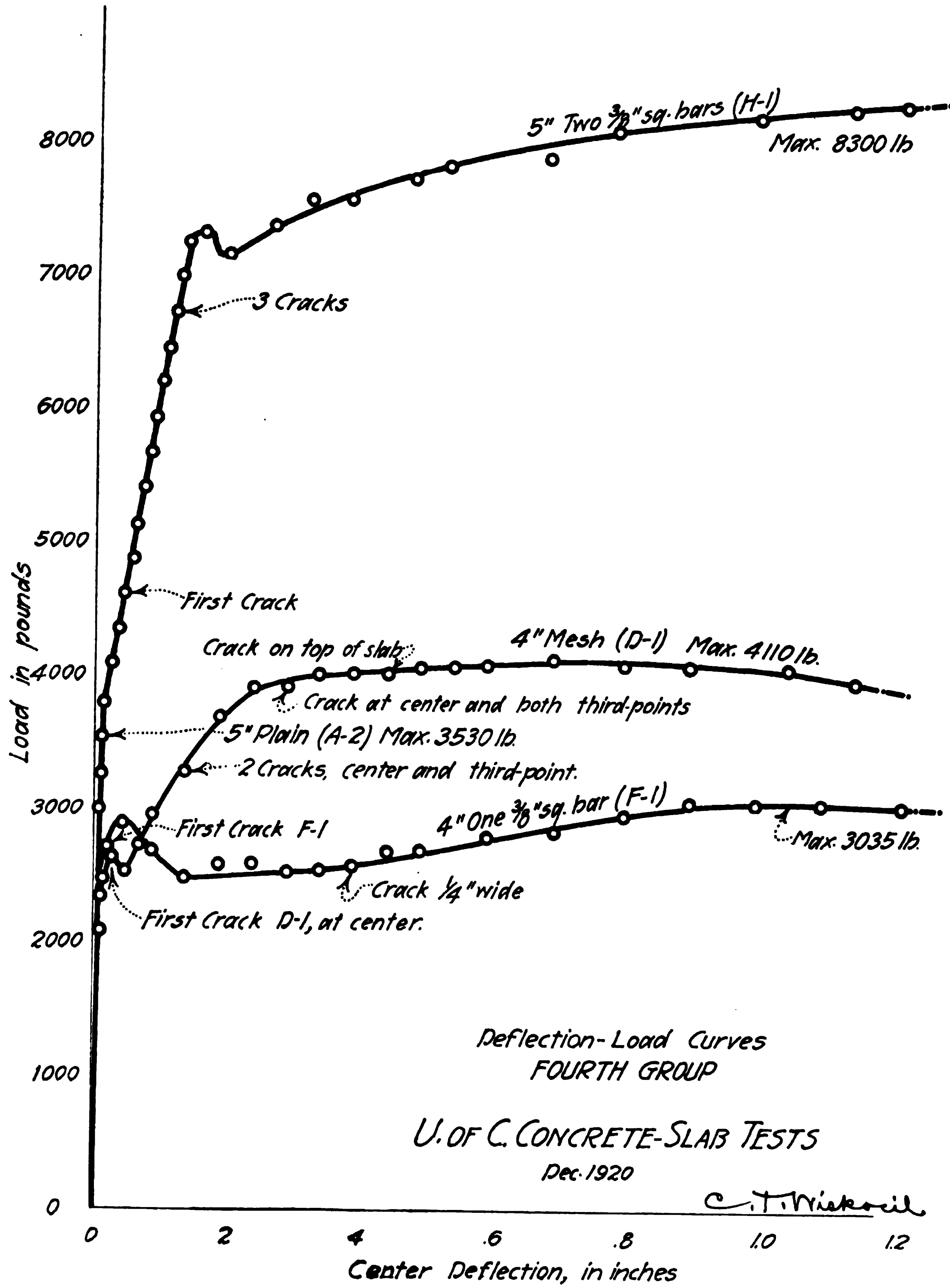

Load in thousands of pounds per square inch
Load in thousands of pounds
Deformation in inches, 10 inch gage length.
Group 1
Group 2
Group 3
Group 4
Group 5
P.L. Group 1
P.L. Group 2
P.L. Group 3
P.L. Group 4
P.L. Group 5
Average values in lb. per sq. in.
Proportional Limit 1,080
Maximum Compressive Strength 2,430
Modulus of Elasticity 2,160,000
Stress Deformation
CONCRETE USED IN SLABS
U. of C. Concrete-Slab Tests
6" by 12" Cylinders
Dec. 1920

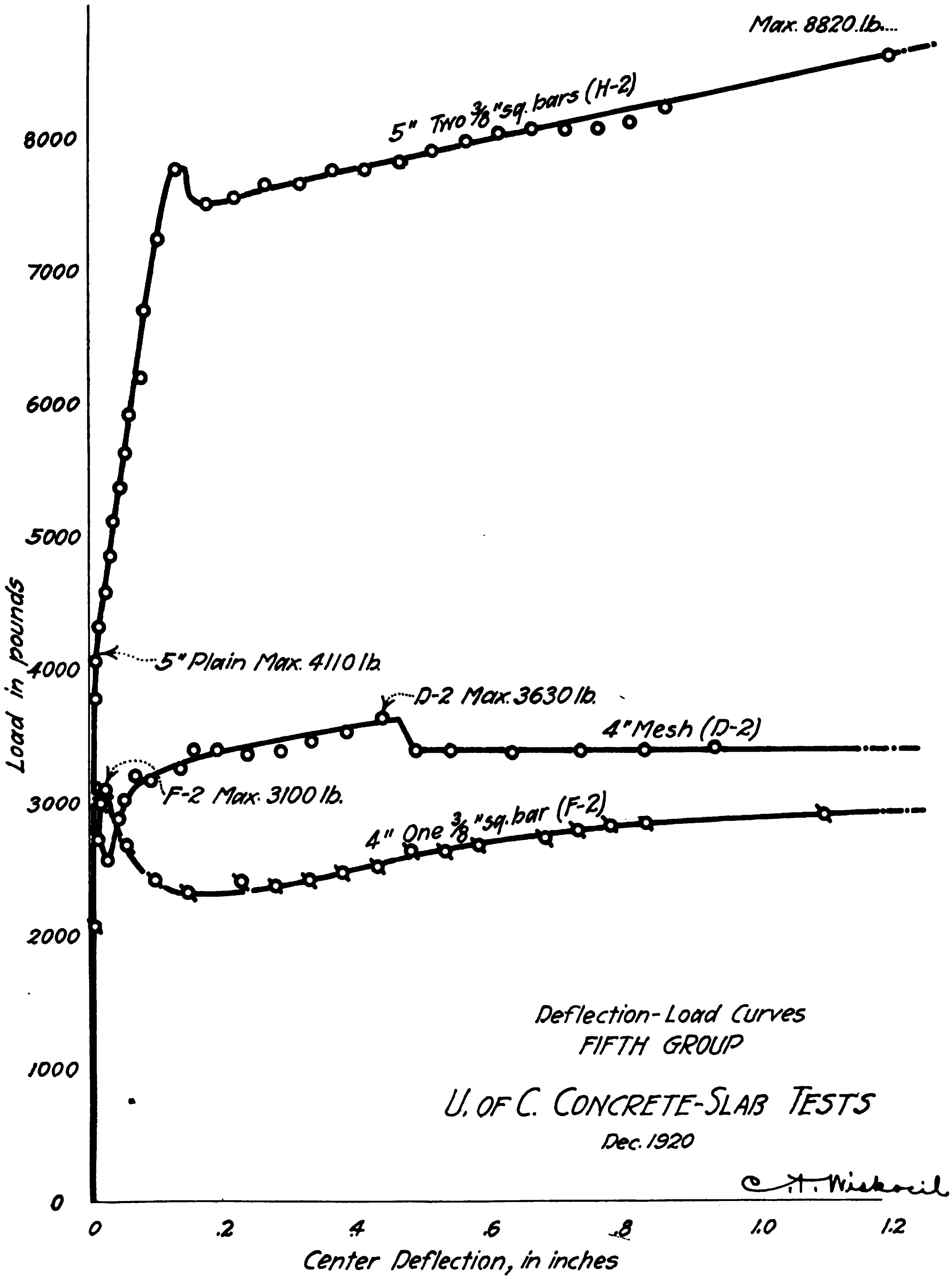


7" Plain (C-1) Max. 7990 lb.
Max. 7370 lb.
5" Mesh (E-1)
Max. 4210 lb.
5" One ⅜" sq. bar (G-1)
5" Plain (A-1) Max. 3310 lb.
Load in pounds
8000
7000
6000
5000
4000
3000
2000
1000
0
.2
.4
.6
.8
1.0
1.2
Center Deflection, in inches
Deflection-Load Curves
FIRST GROUP
U. of C. Concrete-Slab Tests
Dec. 1920


7"Plain (C-2) Max. 9110 lb.
Max. 6940 lb.
5"Mesh (E-2)
6"Plain (B-1) Max. 5720 lb.
Max. 4920 lb.
First Crack
5" One 3/8" sq. bar (G-2)
Crack 1/4" wide
Deflection-Load Curves
Second Group
U. of C. Concrete-Slab Tests
Dec. 1920
Load in pounds
8000
7000
6000
5000
4000
3000
2000
1000
0
0
.2
.4
.6
.8
1.0
1.2
Center Deflection, in inches.


8000
7000
6000
5000
4000
3000
2000
1000
0
Load in pounds
7"Plain (C-3) Max. 7570 lb.
3 Cracks
5"Mesh (E-3)
Max. 6140 lb.
2 Cracks
6"Plain (B-2) Max. 5990 lb.
First Crack
5" One 7/8" sq. bar (G-3)
Max. 4610 lb.
Crack 1/4" wide
First Crack
Load-Deflection Curves
THIRD GROUP
U. of C. Concrete-Slab Tests
Dec. 1920
C. T. Wiskocil
0
.2
.4
.6
.8
1.0
1.2
Center Deflection, in inches


5" Two 3/8"sq. bars (H-1)
Max. 8300 lb
3 Cracks
First Crack
Crack on top of slab
4" Mesh (D-1) Max. 4110 lb.
Crack at center and both third-points
5" Plain (A-2) Max. 3530 lb.
2 Cracks, center and third-point.
First Crack F-1
4" One 3/8"sq. bar (F-1)
Max. 3035 lb.
Crack 1/4" wide
First Crack D-1, at center.
Deflection-Load Curves
FOURTH GROUP
U. OF C. CONCRETE-SLAB TESTS
Dec. 1920
C. T. Wiskocil
Load in pounds
0
1000
2000
3000
4000
5000
6000
7000
8000
0
.2
.4
.6
.8
1.0
1.2
Center Deflection, in inches


Max. 8820.lb.
5" Two 3/8"sq. bars (H-2)
8000
7000
6000
5000
4000
3000
2000
1000
0
Load in pounds
5" Plain Max. 4110 lb.
D-2 Max. 3630 lb.
4" Mesh (D-2)
F-2 Max. 3100 lb.
4" One 3/8"sq. bar (F-2)
Deflection-Load Curves
FIFTH GROUP
U. OF C. CONCRETE-SLAB TESTS
Dec. 1920
0
.2
.4
.6
.8
1.0
1.2
Center Deflection, in inches

Discussion of Results:

The proportional limit was taken as that load on the Deflection-Load curve at which the curve deviated from a straight line. This point might have been called the "elastic limit." Some other arbitrary point, such as the apparent elastic limit or useful limit, might have been taken but it was decided to use the proportional limit—the maximum load at which the load ceased to be proportional to the deflection. For practical purposes this point may be taken as the maximum load which a slab will carry without being permanently deformed.

The first crack was observed at 0.02 inches deflection in the 4-inch slab. From the shape of the curves for the five-inch slabs the first crack would appear at approximately the same deflection. The first crack in the five-inch reinforced slab was at a deflection of 0.03 inches. (Slab G-2.)

A crack must have appreciable width before it can be seen by the observer whose chief duty is to read the deflection. If the testing machine had been stopped after each increment of load had been applied it would have been possible to make a careful search for cracks and they might have been found at smaller deflections.

No plain slab reached a deflection of 0.02 inches under load. In slabs of this type, first crack means failure of the lower fibers in tension and hence failure of the entire slab. The maximum load, therefore, is taken as the load at first crack for the plain slabs.

The plain slabs broke near the center of the span and practically straight across the slab. Figure 3 is the most irregular break; it is typical, however, in showing the absence of any secondary cracks. These slabs showed very small deflections. The maximum which was less than 15 thousandths of an inch is so small that it can be detected only by accurate measurement. Nevertheless the Deflection-Load curves obtained show a decided proportional limit.

Slabs reinforced with one bar. (Bar at center of slab's width.) These slabs showed peculiar action under load. They carried load up to the proportional limit with practically the same deflections as those observed for plain slabs and for those reinforced with mesh. After the proportional limit was passed the deflection increased rapidly and the load increased to its maximum value at about 0.04-inch deflection. After this deflection was reached the load dropped off suddenly but recovered practically its maximum value at 1.2-inch deflection. At a deflection of 0.3-inch the first crack, which first appeared at a deflection of approximately 0.02-inch was $\frac{1}{4}$-inch wide on the lower side of the slab.

The secondary cracks in Figure 5 did not develop during the test; they were formed later when the slab was bent in an attempt to break the bar. The one-bar slabs showed only one crack.

Slabs reinforced with two bars. (Bars placed $4\frac{1}{2}$ inches on each side of center of slab.) The two-bar slabs sustained the greatest loads. The maximum strength, however, was not developed until the deflection had exceeded 1.2 inches. At this deflection the bottom of the slab had the appearance of Figure 6. The three transverse cracks were in the slab at a deflection of 0.12 inches. The secondary or longitudinal cracks were not apparent until the maximum load was reached. The first crack, near the center of the span, was observed at a deflection of 0.04 inches and the other two cracks, both between the third-points became visible at a deflection of 0.12 inches as previously stated.

The drop in the Load-Deflection curve was much smaller than that for the one-bar slabs.

Slabs reinforced with mesh. These slabs developed their greatest load after being cracked in three places—all within the third-points. Only the 4-inch slabs showed the sudden dropping of the load which characterized the one-bar slab curves. The first crack always

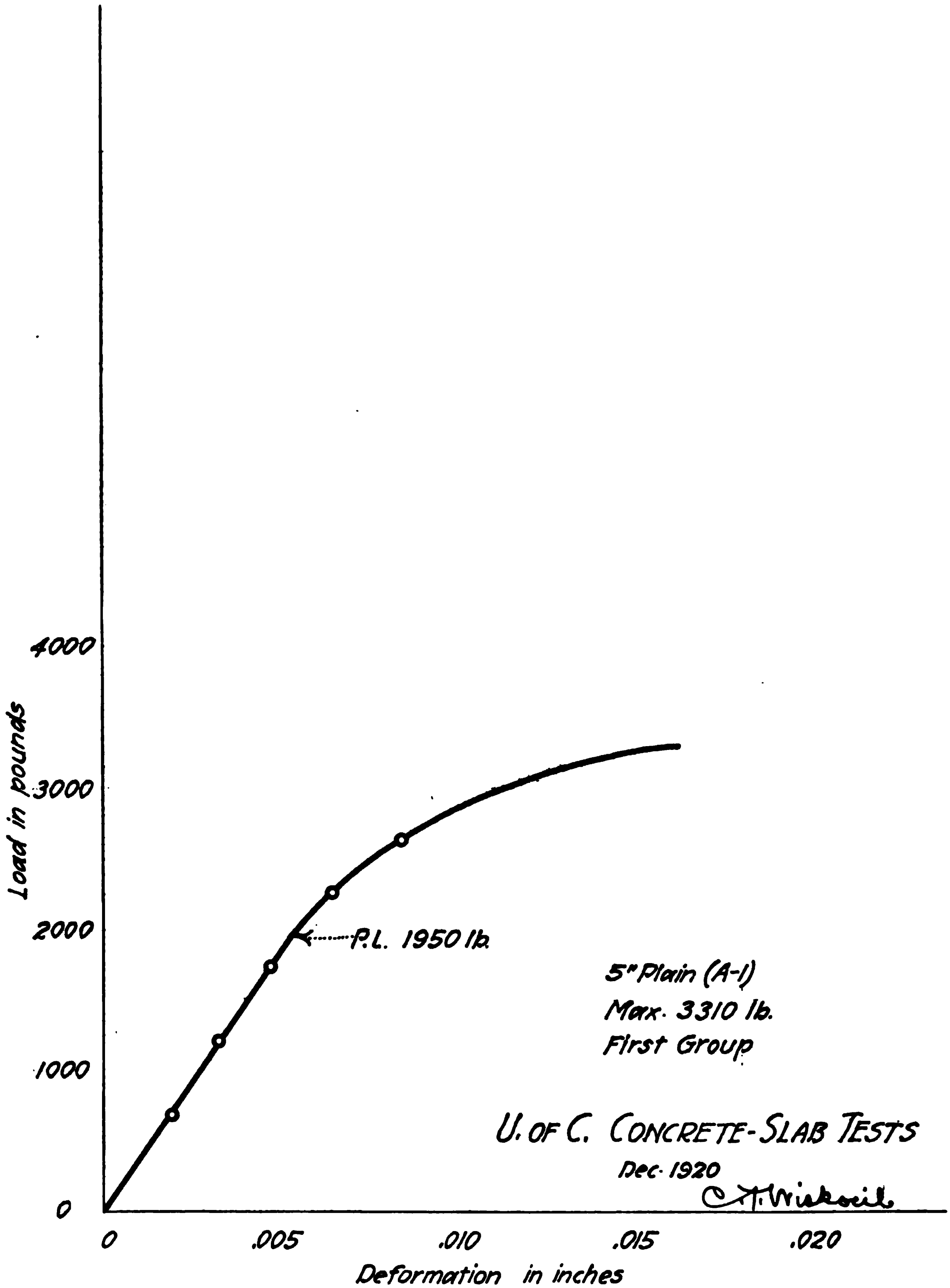
came at the center; the slab, however, did not always fail at the center as shown in Figure 4. All mesh-slabs developed three distinct cracks at deflections less than 0.3 inches.

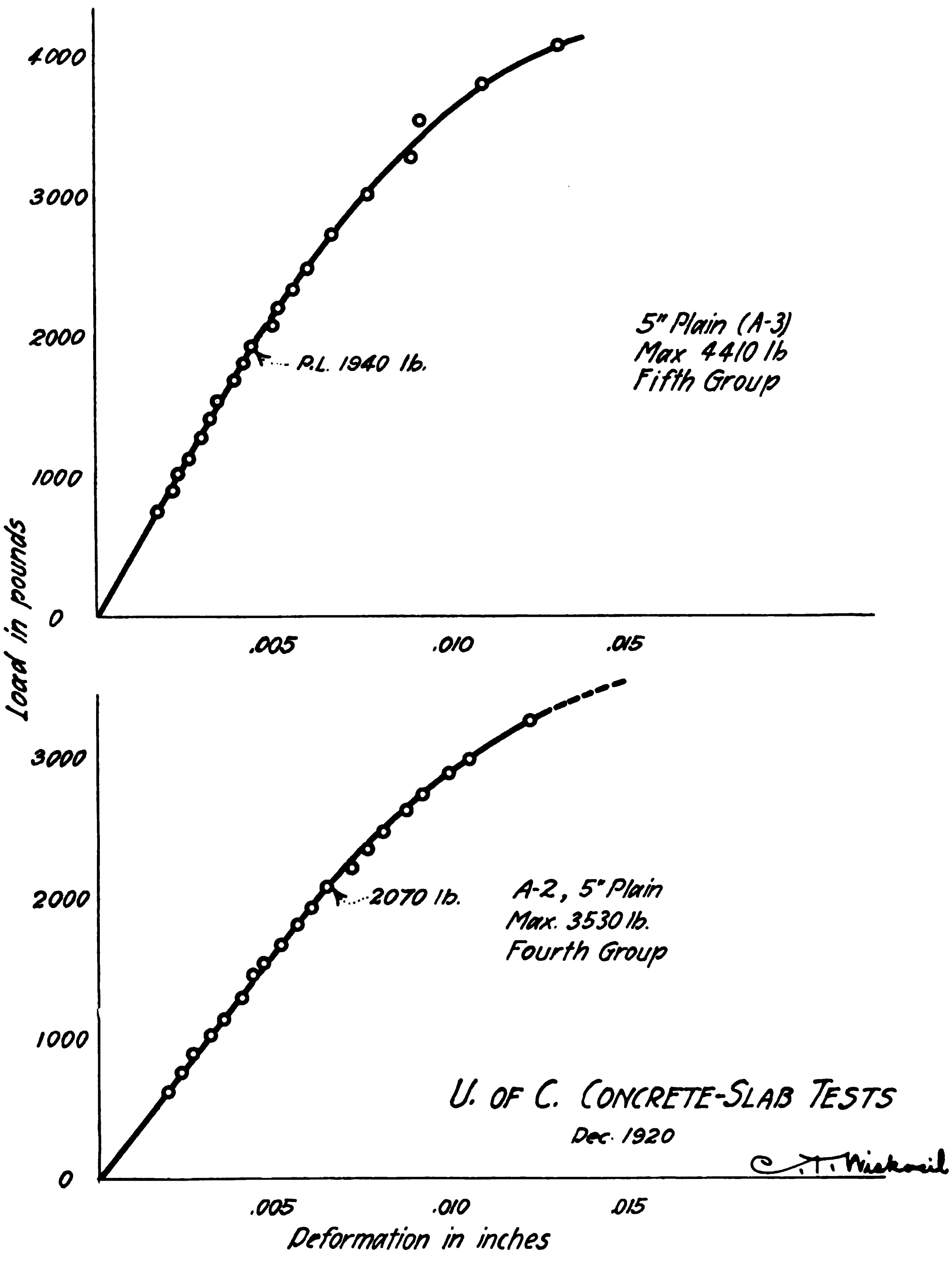
Conclusions:

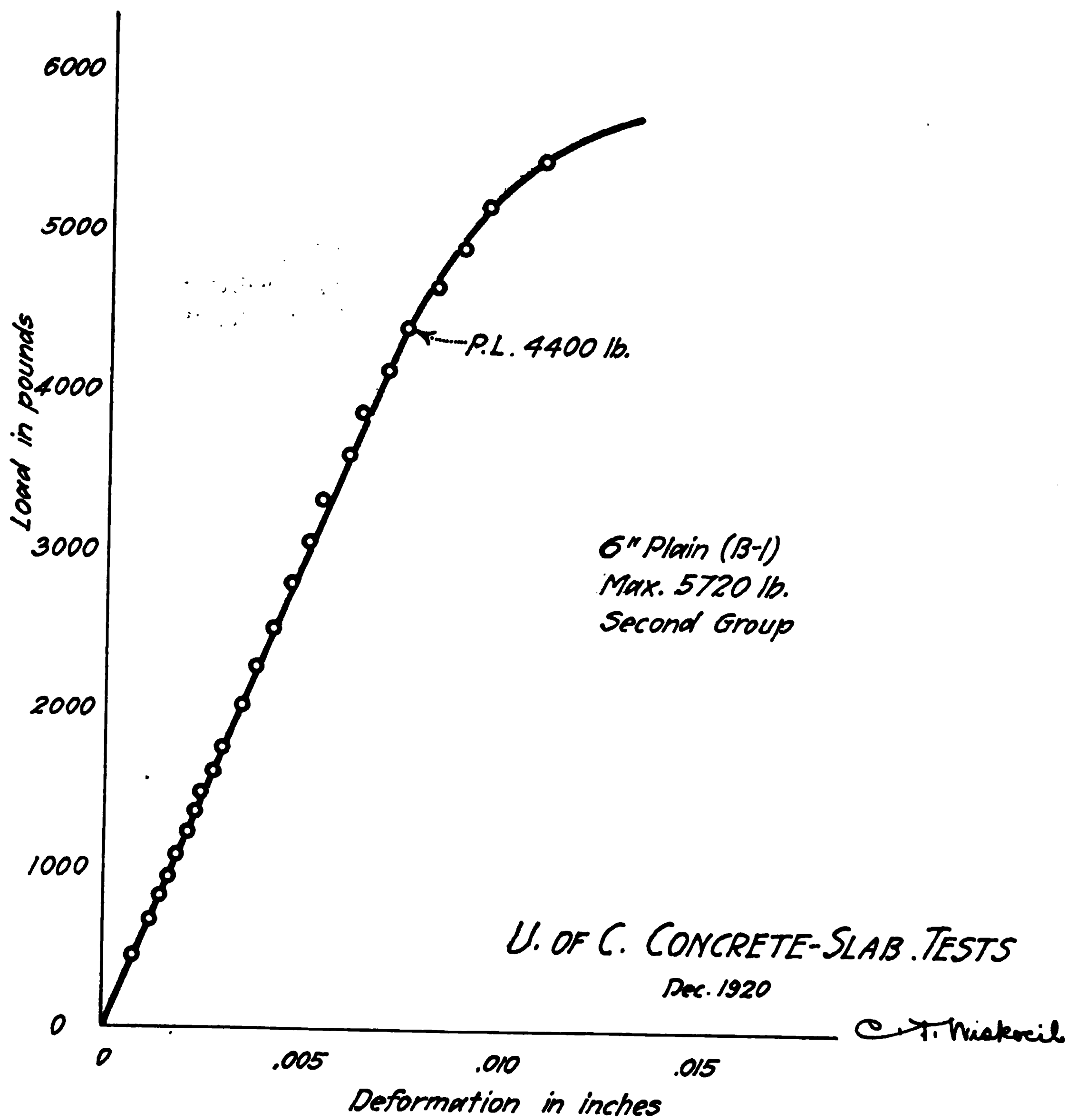
The large-scale Load-Deflection curves show that the proportional limit is the most reliable basis for comparison of slab strengths.

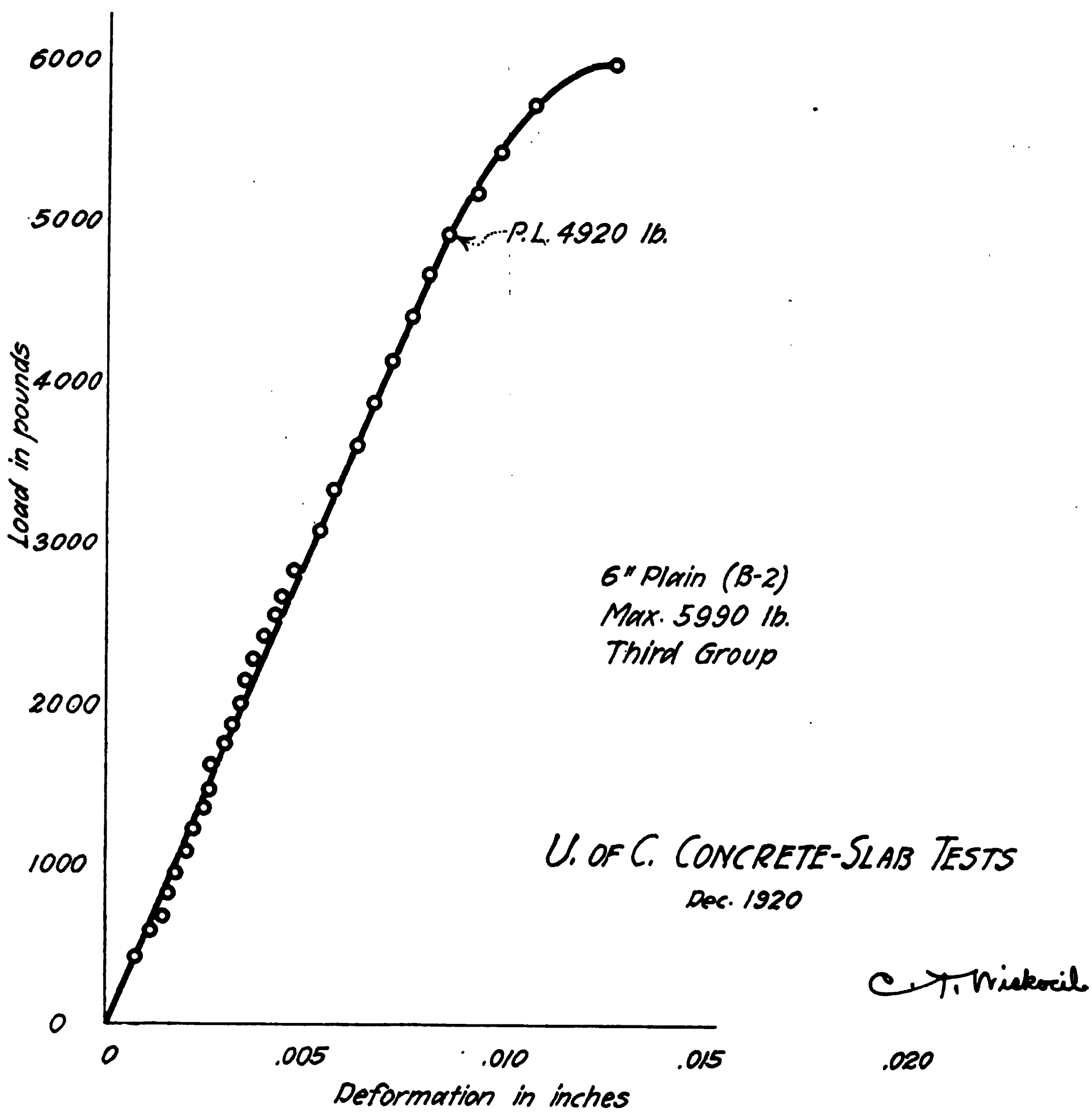
The reinforced slabs are not as strong as plain slabs one inch thicker. (At their respective proportional limits.)

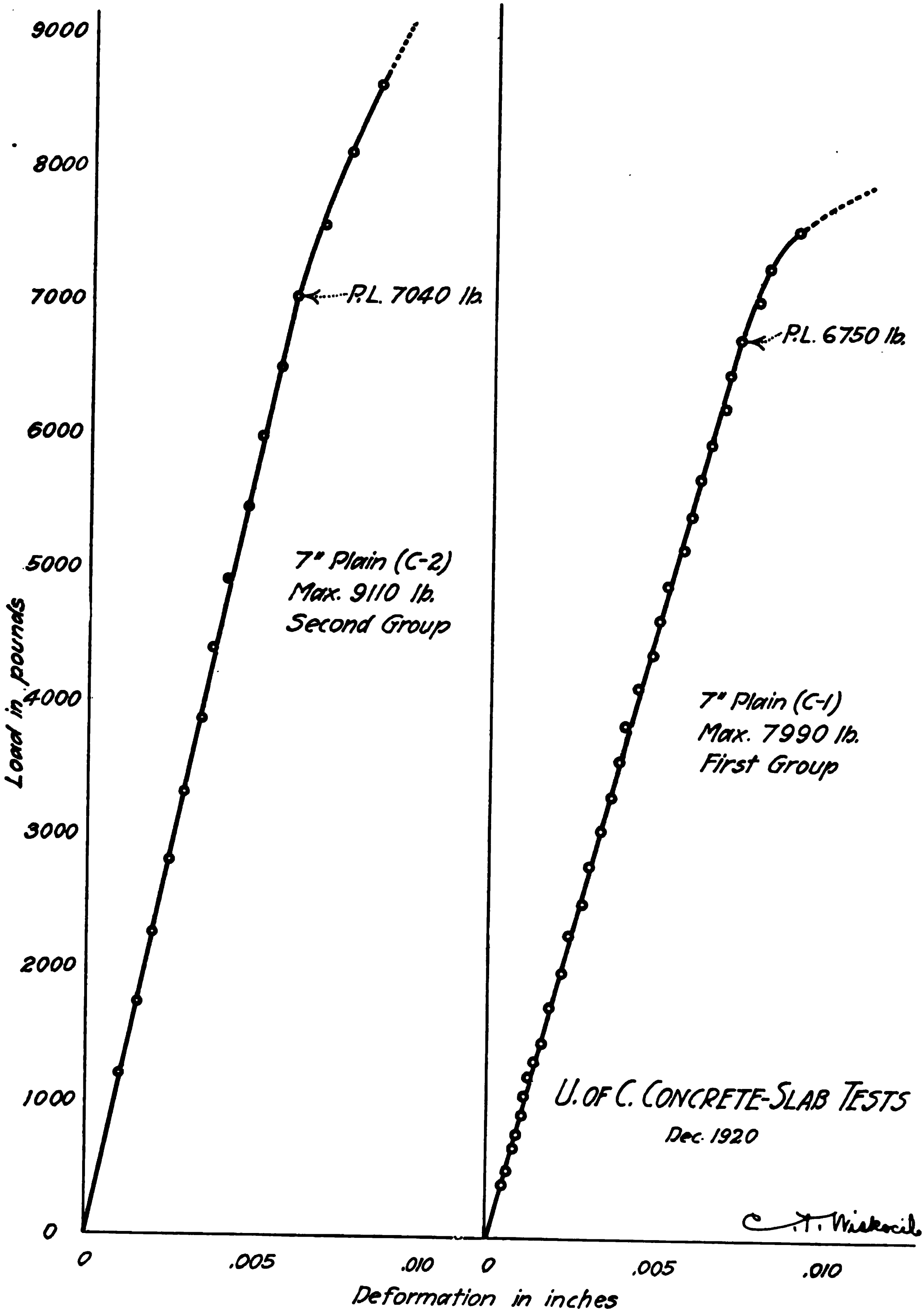
At the proportional limit, reinforced slabs 4 and 5 inches thick had less than 50 per cent the strength of plain slabs 6 and 7 inches thick. The two inches of extra concrete practically doubled the strength of the plain slabs.

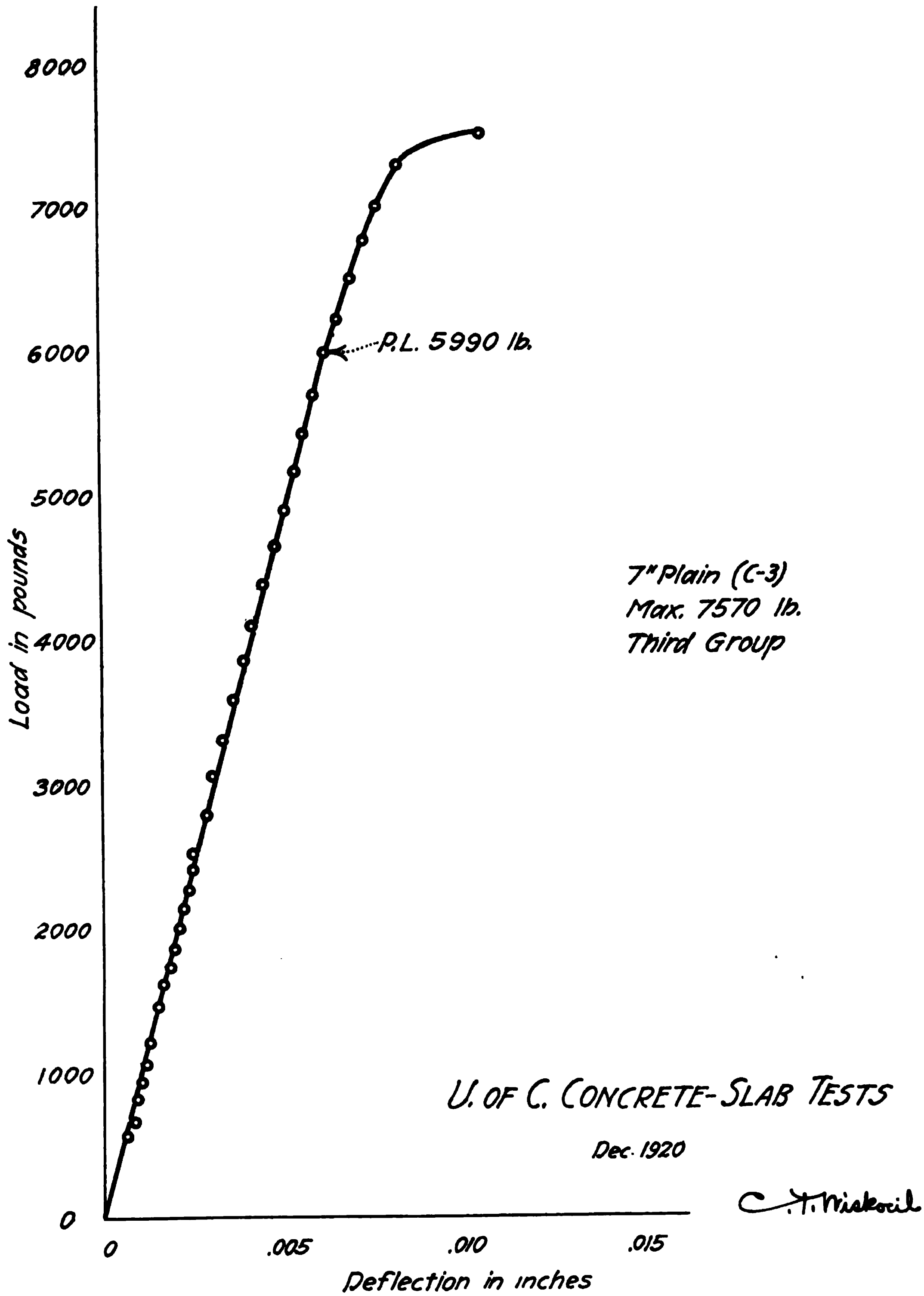

4000
3000
2000
1000
0
Load in pounds
P.L. 1950 lb.
5" Plain (A-1)
Max. 3310 lb.
First Group
U. of C. Concrete-Slab Tests
Dec. 1920
0
.005
.010
.015
.020
Deformation in inches

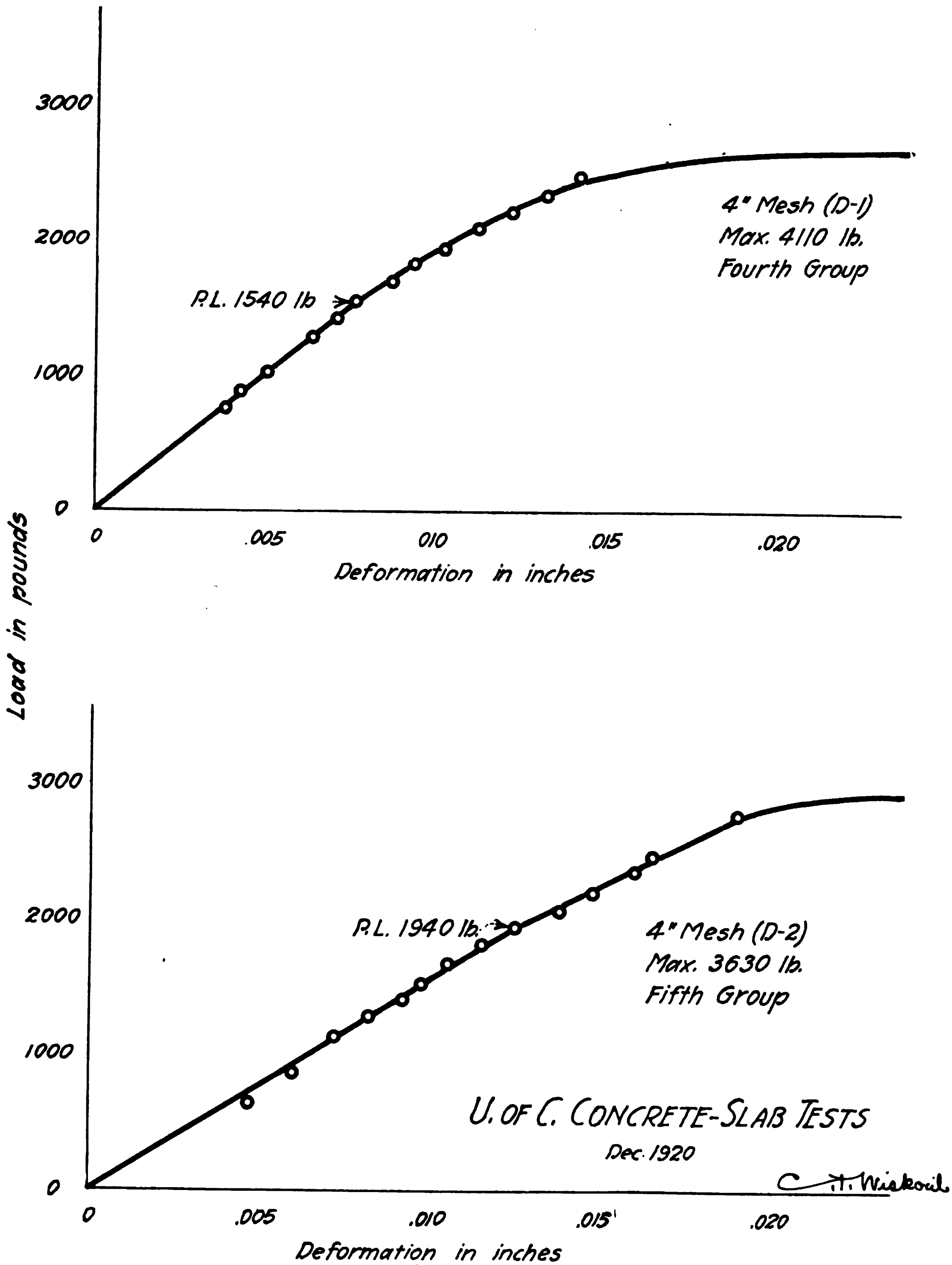

4000
3000
2000
1000
0
P.L. 1940 lb.
5" Plain (A-3)
Max 4410 lb
Fifth Group
.005
.010
.015
Load in pounds
3000
2000
1000
0
2070 lb.
A-2, 5" Plain
Max. 3530 lb.
Fourth Group
U. of C. Concrete-Slab Tests
Dec. 1920
.005
.010
.015
Deformation in inches


6000
5000
4000
3000
2000
1000
0
Load in pounds
P.L. 4400 lb.
6" Plain (B-1)
Max. 5720 lb.
Second Group
U. of C. Concrete-Slab Tests
Dec. 1920
0
.005
.010
.015
Deformation in inches

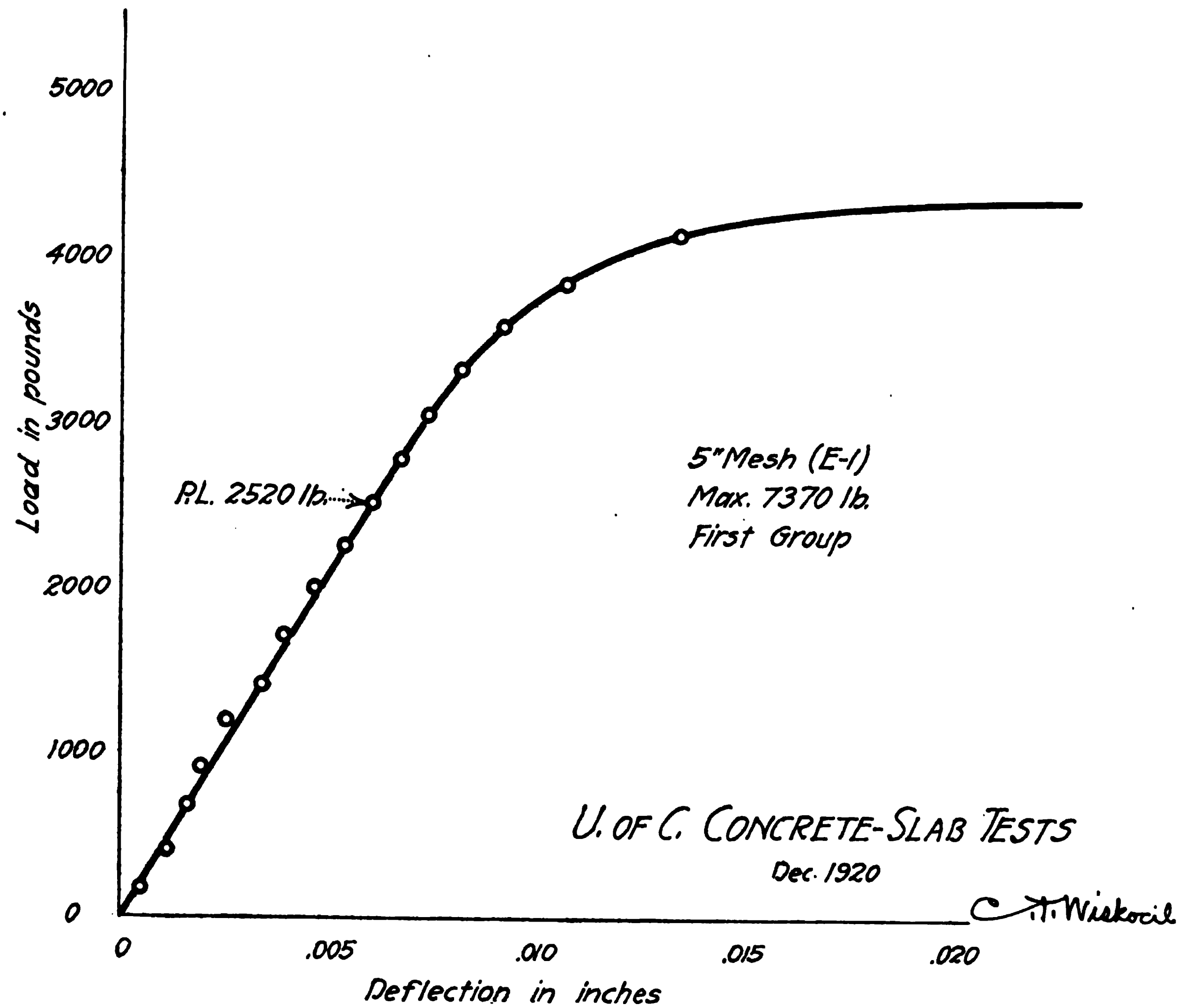

6000
5000
4000
3000
2000
1000
0
Load in pounds
0
.005
.010
.015
.020
Deformation in inches
P.L. 4920 lb.
6" Plain (B-2)
Max. 5990 lb.
Third Group
U. of C. Concrete-Slab Tests
Dec. 1920

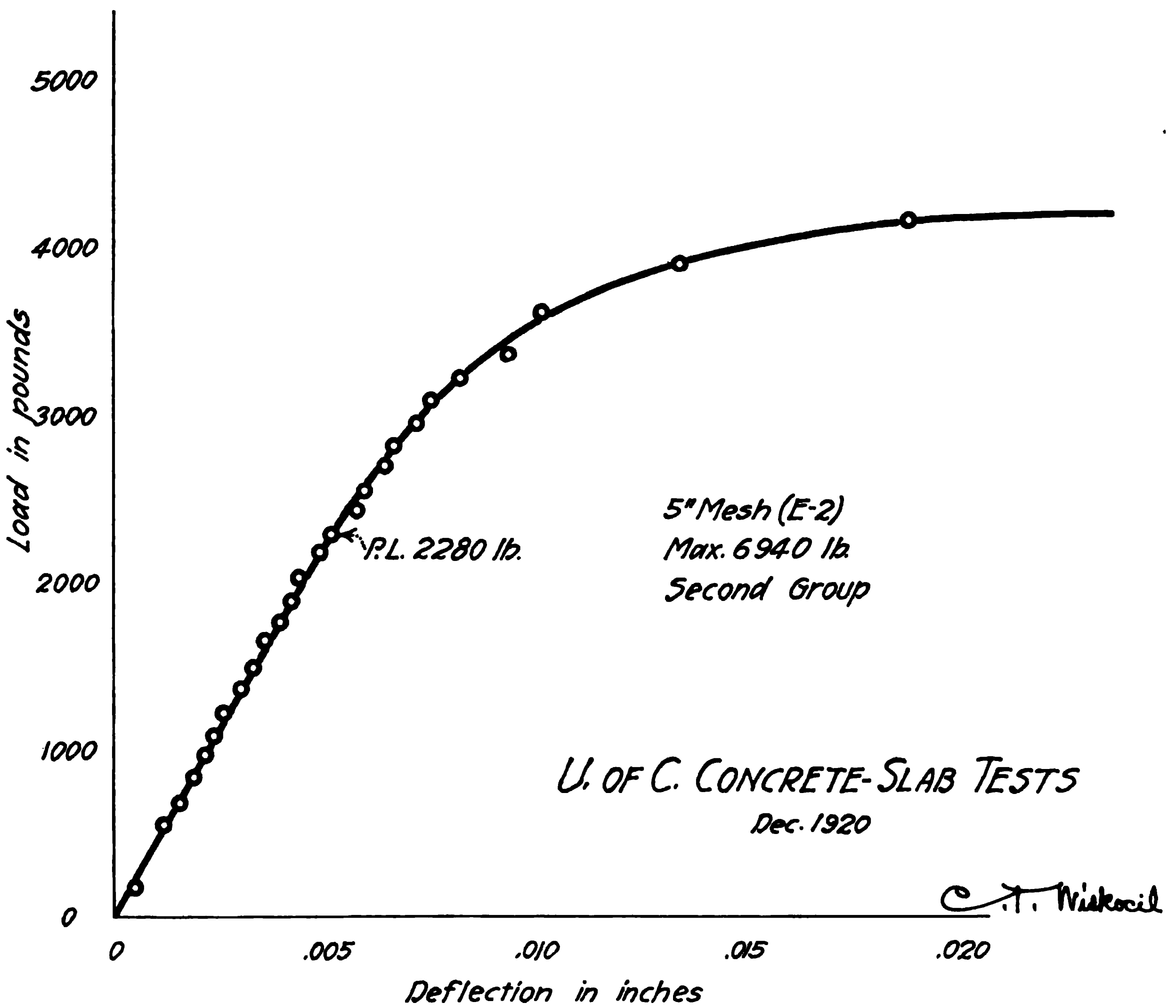

9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Load in pounds
P.L. 7040 lb.
7" Plain (C-2)
Max. 9110 lb.
Second Group
P.L. 6750 lb.
7" Plain (C-1)
Max. 7990 lb.
First Group
U. of C. Concrete-Slab Tests
Dec. 1920
C. T. Wiskocil
0
.005
.010
0
.005
.010
Deformation in inches

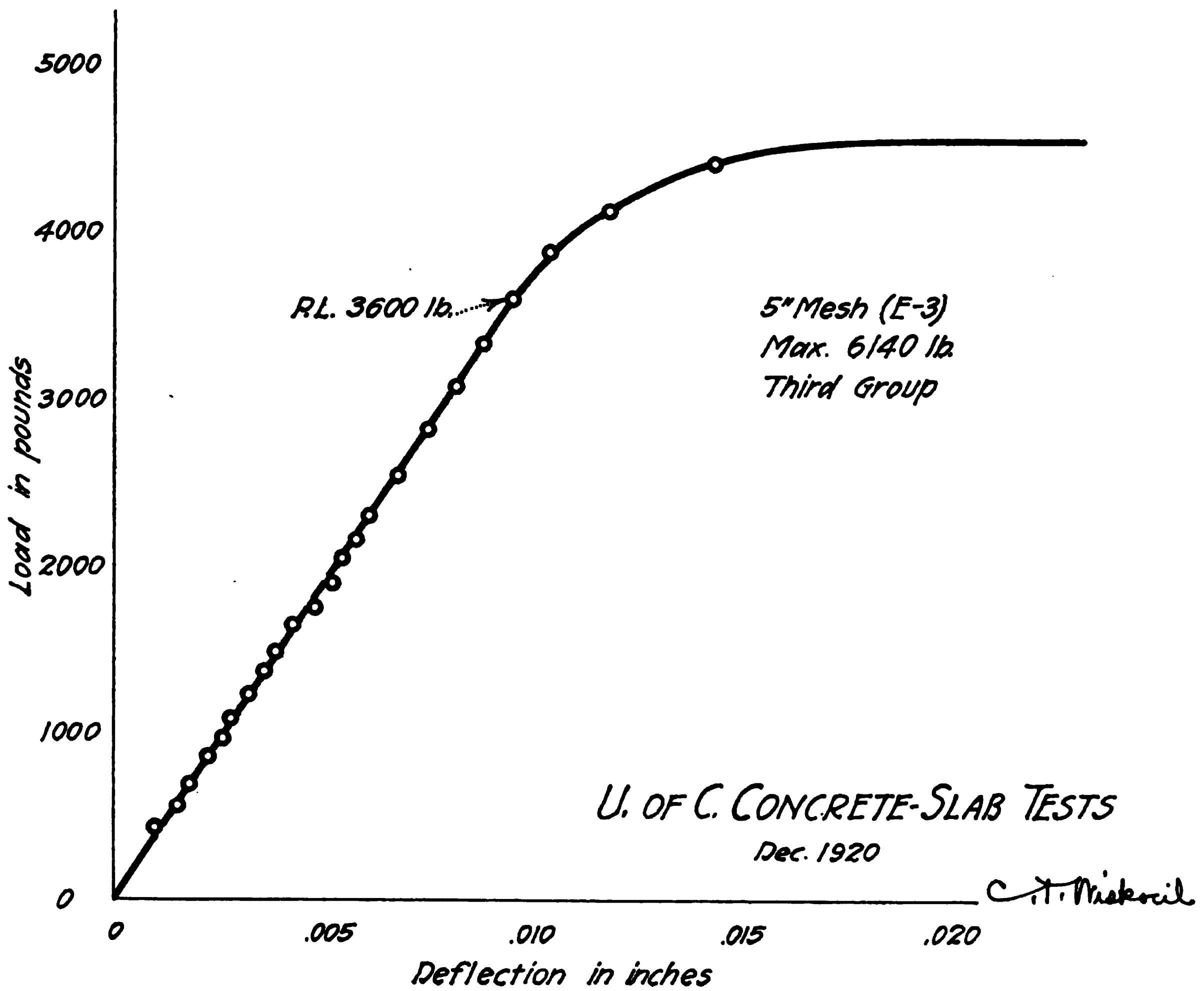

8000
7000
6000
5000
4000
3000
2000
1000
0
Load in pounds
P.L. 5990 lb.
7" Plain (C-3)
Max. 7570 lb.
Third Group
U. of C. Concrete-Slab Tests
Dec. 1920
C. T. Wiskocil
0
.005
.010
.015
Deflection in inches



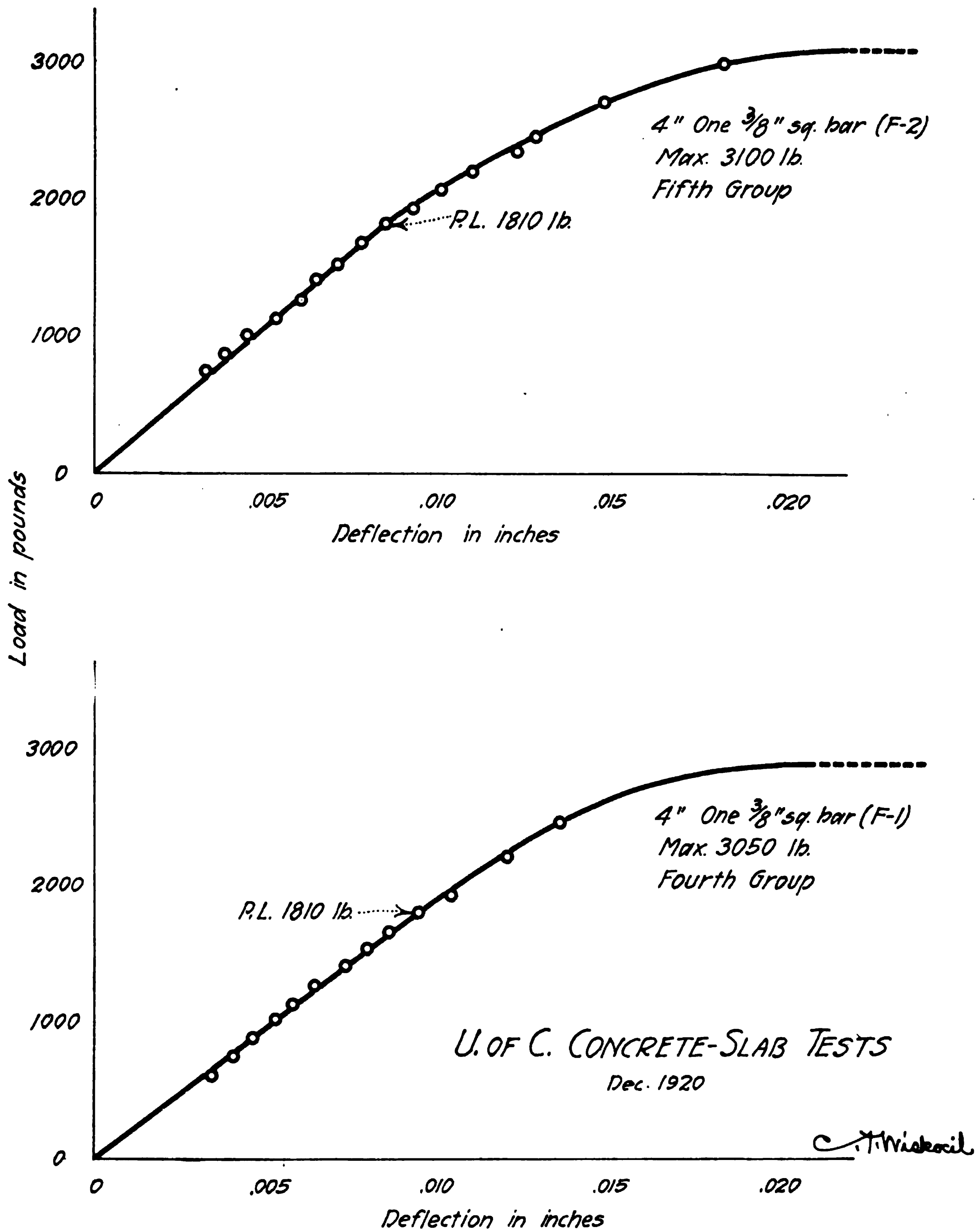
3000
2000
1000
0
0
.005
.010
.015
.020
Deformation in inches
Load in pounds
P.L. 1540 lb
4" Mesh (D-1)
Max. 4110 lb.
Fourth Group
3000
2000
1000
0
0
.005
.010
.015
.020
Deformation in inches
P.L. 1940 lb.
4" Mesh (D-2)
Max. 3630 lb.
Fifth Group
U. of C. Concrete-Slab Tests
Dec. 1920
C. H. Wiskocil

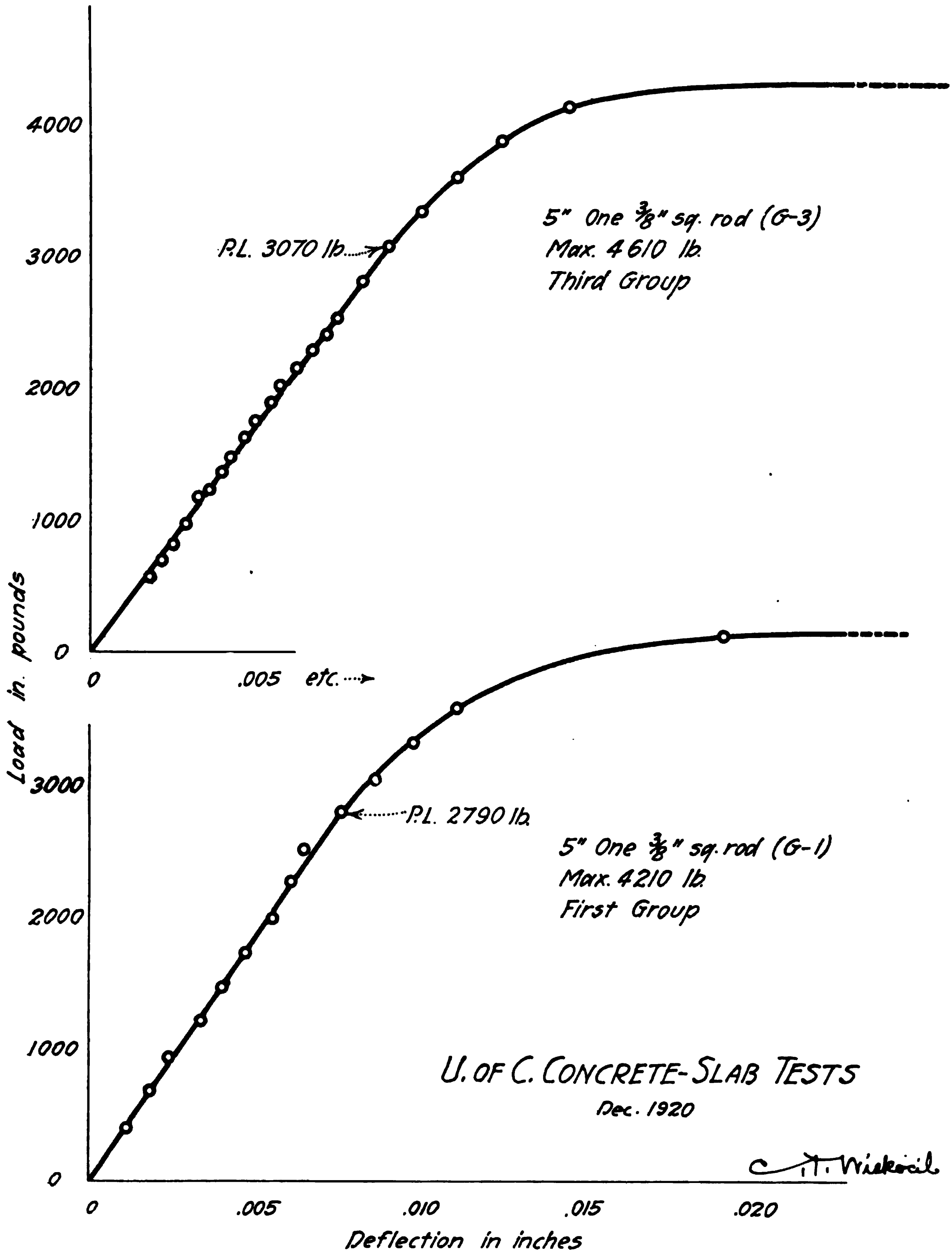

5000
4000
3000
2000
1000
0
Load in pounds
P.L. 2520 lb.
5" Mesh (E-1)
Max. 7370 lb.
First Group
U. of C. Concrete-Slab Tests
Dec. 1920
C. T. Wiskocil
0
.005
.010
.015
.020
Deflection in inches


5000
4000
3000
2000
1000
0
Load in pounds
0
.005
.010
.015
.020
Deflection in inches
P.L. 2280 lb.
5" Mesh (E-2)
Max. 6940 lb.
Second Group
U. of C. Concrete-Slab Tests
Dec. 1920
C. T. Wiskocil

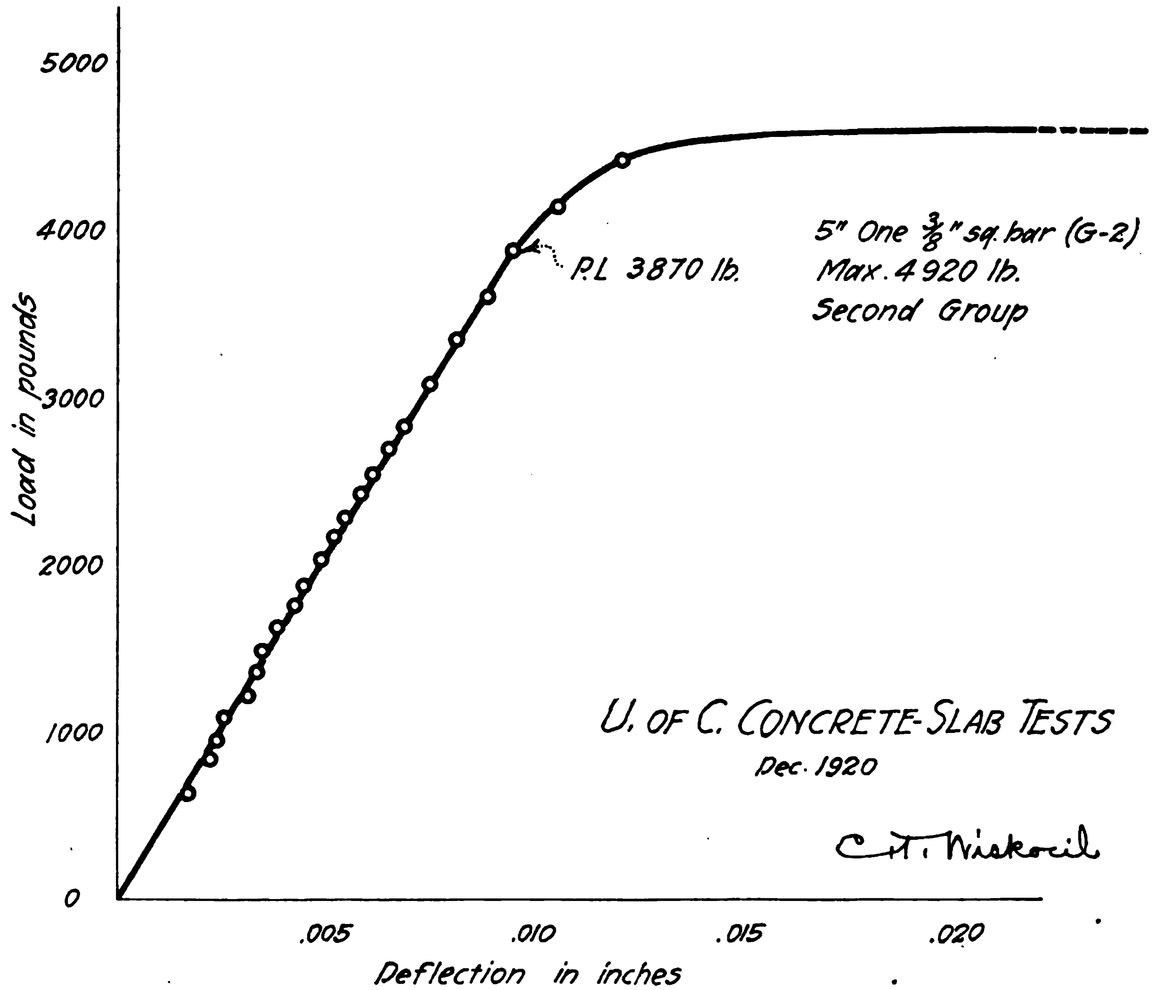


5000
4000
3000
2000
1000
0
Load in pounds
P.L. 3600 lb.
5" Mesh (E-3)
Max. 6140 lb.
Third Group
U. OF C. CONCRETE-SLAB TESTS
Dec. 1920
C. T. Miskocil
0
.005
.010
.015
.020
Deflection in inches

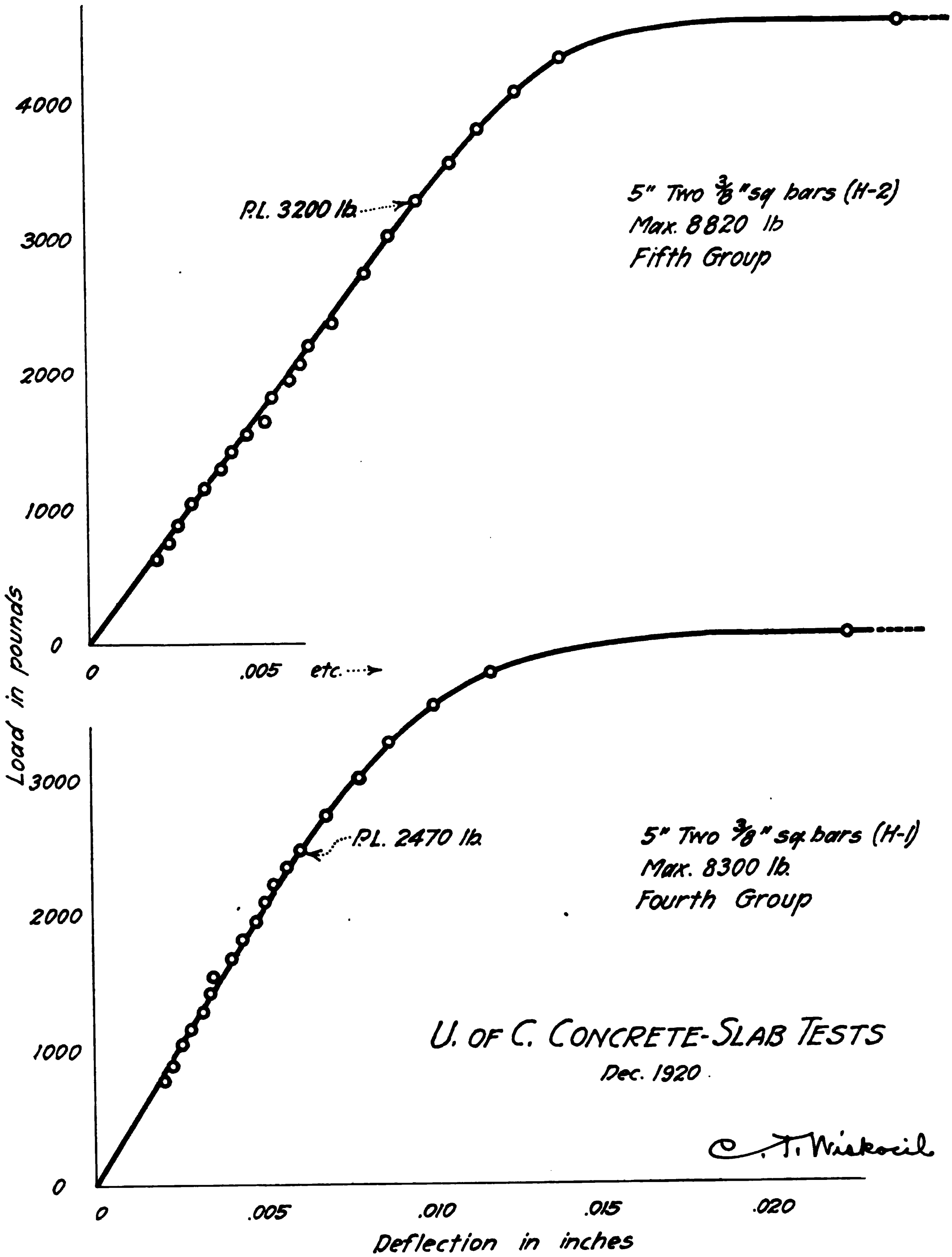

Load in pounds
3000
2000
1000
0
0
.005
.010
.015
.020
Deflection in inches
4" One 3/8" sq. bar (F-2)
Max. 3100 lb.
Fifth Group
P.L. 1810 lb.
4" One 3/8" sq. bar (F-1)
Max. 3050 lb.
Fourth Group
P.L. 1810 lb.
U. of C. Concrete-Slab Tests
Dec. 1920
C. T. Wiskocil



4000
3000
2000
1000
0
P.L. 3070 lb.
5" One 3/8" sq. rod (G-3)
Max. 4610 lb.
Third Group
0
.005
etc.
Load in pounds
3000
2000
1000
0
P.L. 2790 lb.
5" One 3/8" sq. rod (G-1)
Max. 4210 lb.
First Group
U. OF C. CONCRETE-SLAB TESTS
Dec. 1920
0
.005
.010
.015
.020
Deflection in inches



5000
4000
3000
2000
1000
0
Load in pounds
.005
.010
.015
.020
Deflection in inches
P.L 3870 lb.
5" One 3/8" sq. bar (G-2)
Max. 4920 lb.
Second Group
U. OF C. CONCRETE-SLAB TESTS
Dec. 1920
C. H. Wiskocil



4000
3000
2000
1000
0
P.L. 3200 lb.
5" Two 3/8" sq. bars (H-2)
Max. 8820 lb
Fifth Group
0
.005
etc.
Load in pounds
3000
2000
1000
0
P.L. 2470 lb.
5" Two 3/8" sq. bars (H-1)
Max. 8300 lb.
Fourth Group
U. of C. Concrete-Slab Tests
Dec. 1920
C. T. Wiskocil
0
.005
.010
.015
.020
Deflection in inches

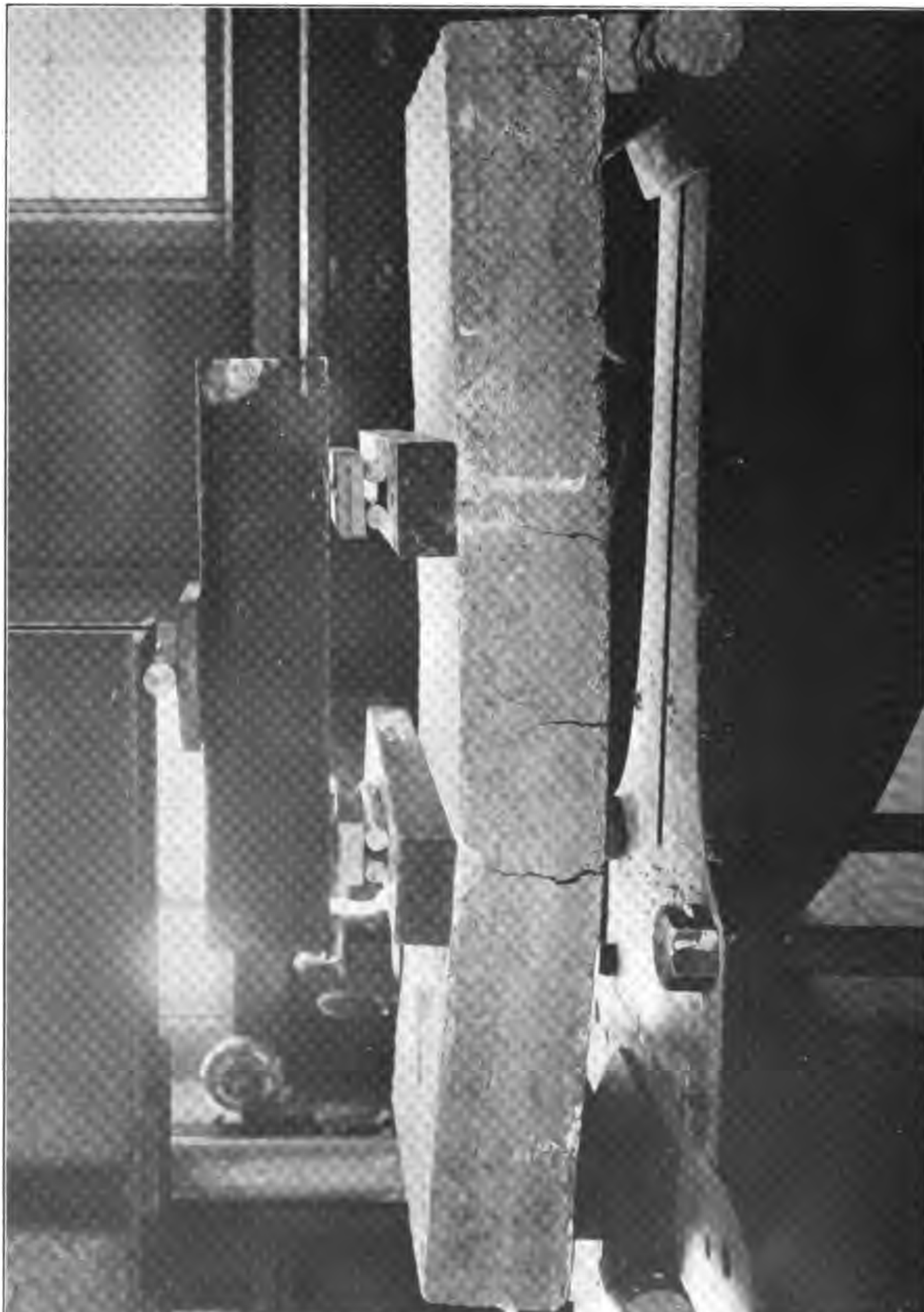


Fig. 1. Slab H-1 in testing machine. Two-bar reinforcement

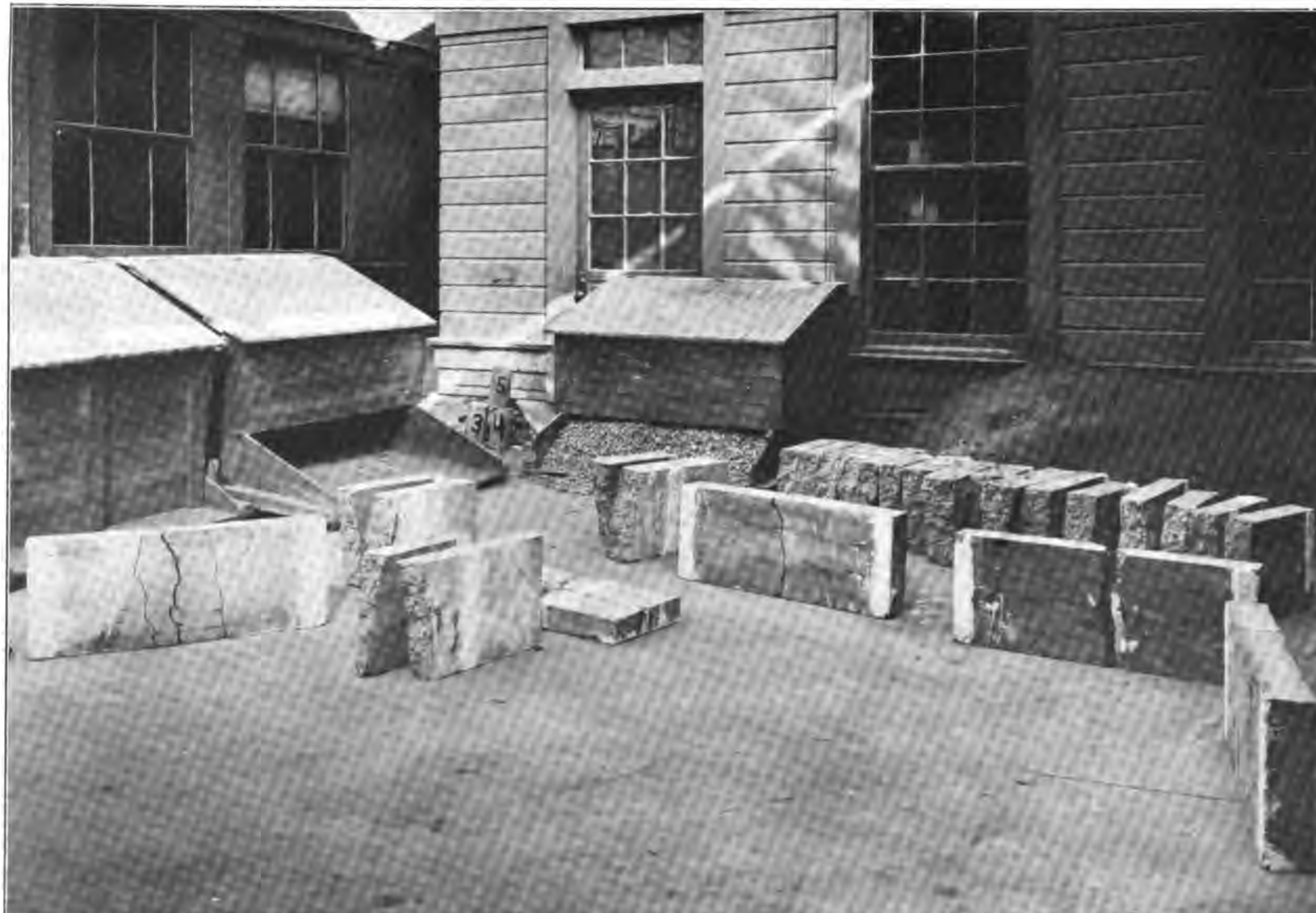


Fig. 2. Slabs after testing: Groups 1 to 4 inclusive

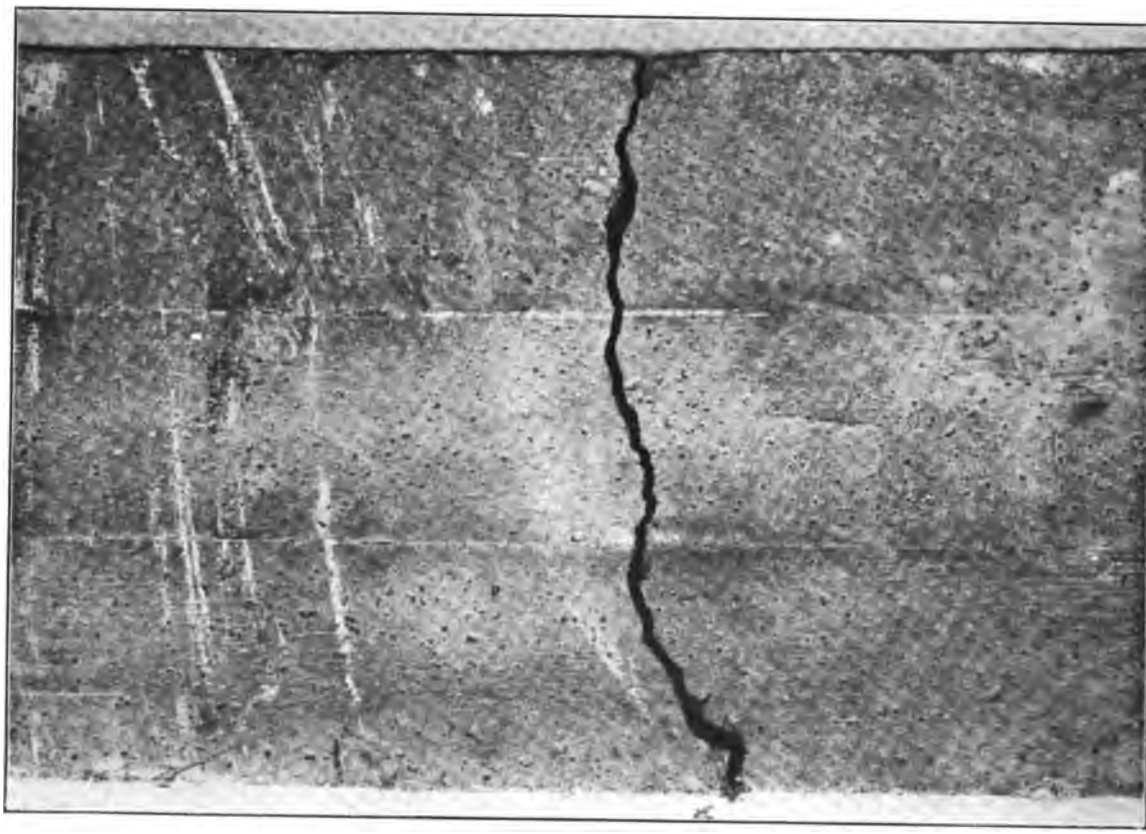


Fig. 3. Slab B-2, no reinforcement

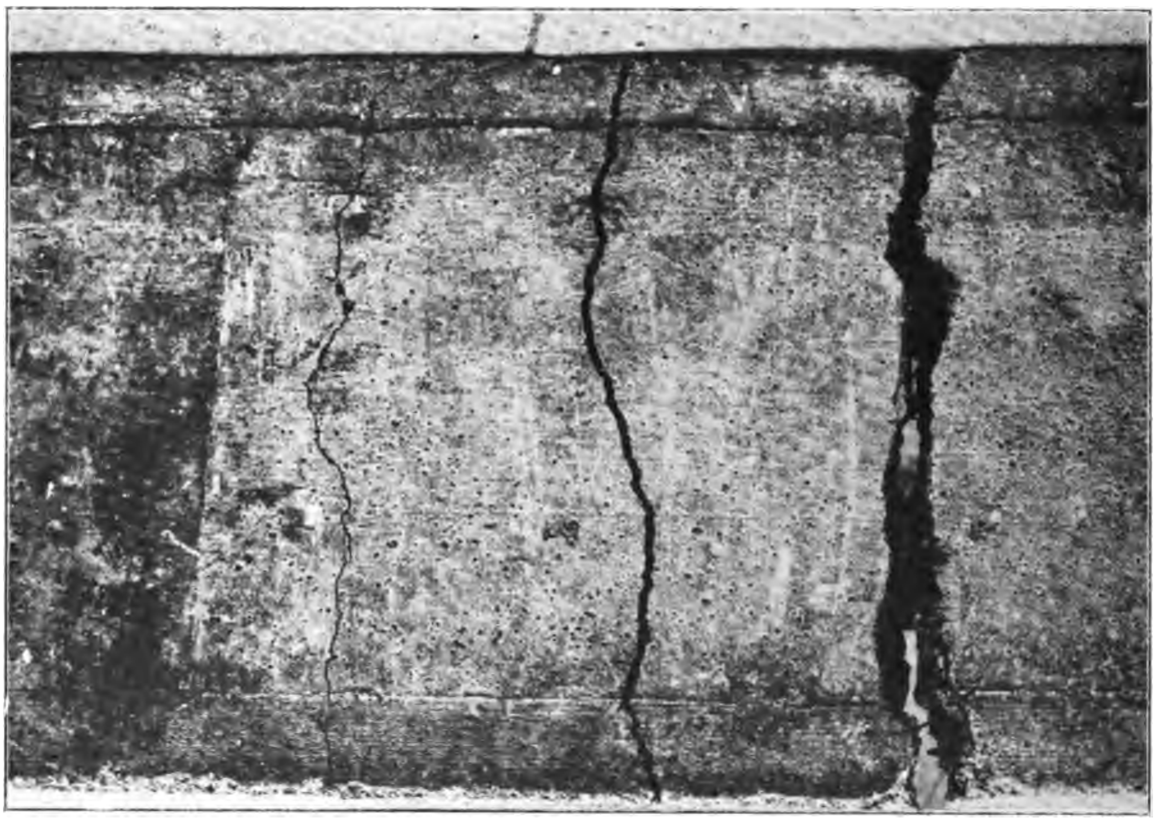


Fig. 4. Slab E-3, wire mesh reinforcement

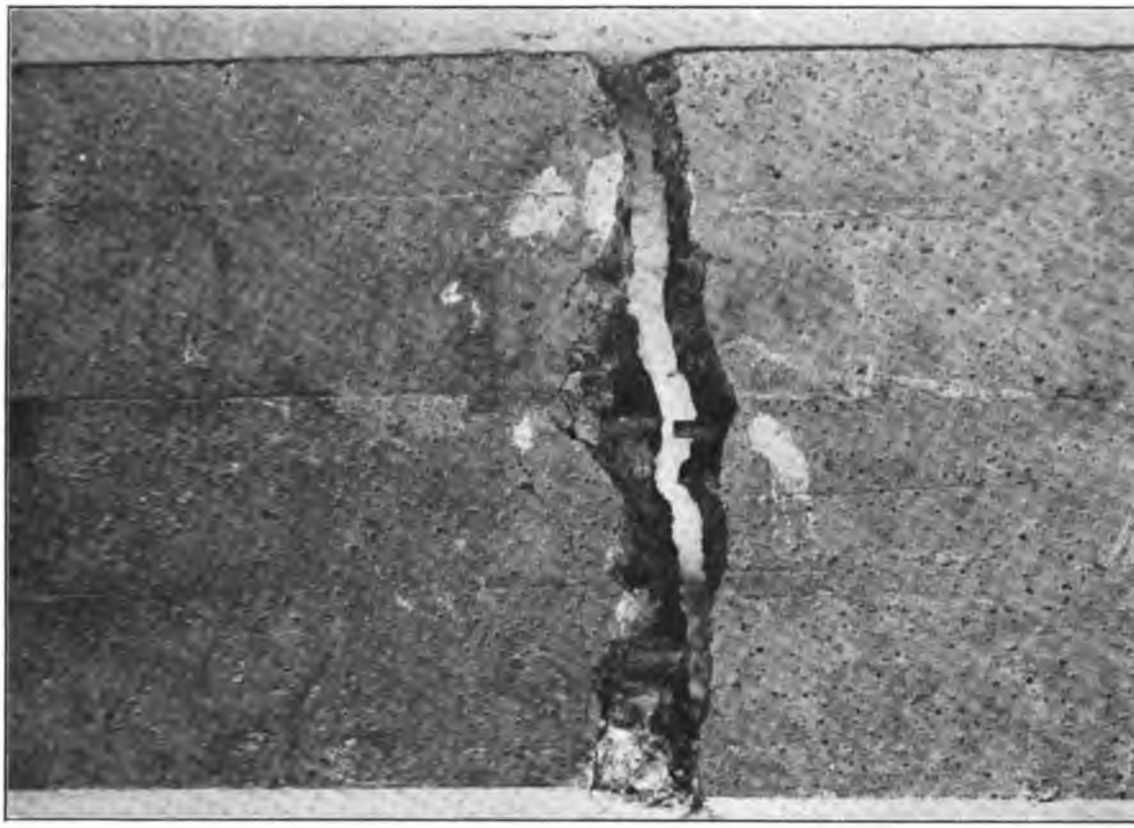


Fig. 5. Slab G-3, one-bar reinforcement

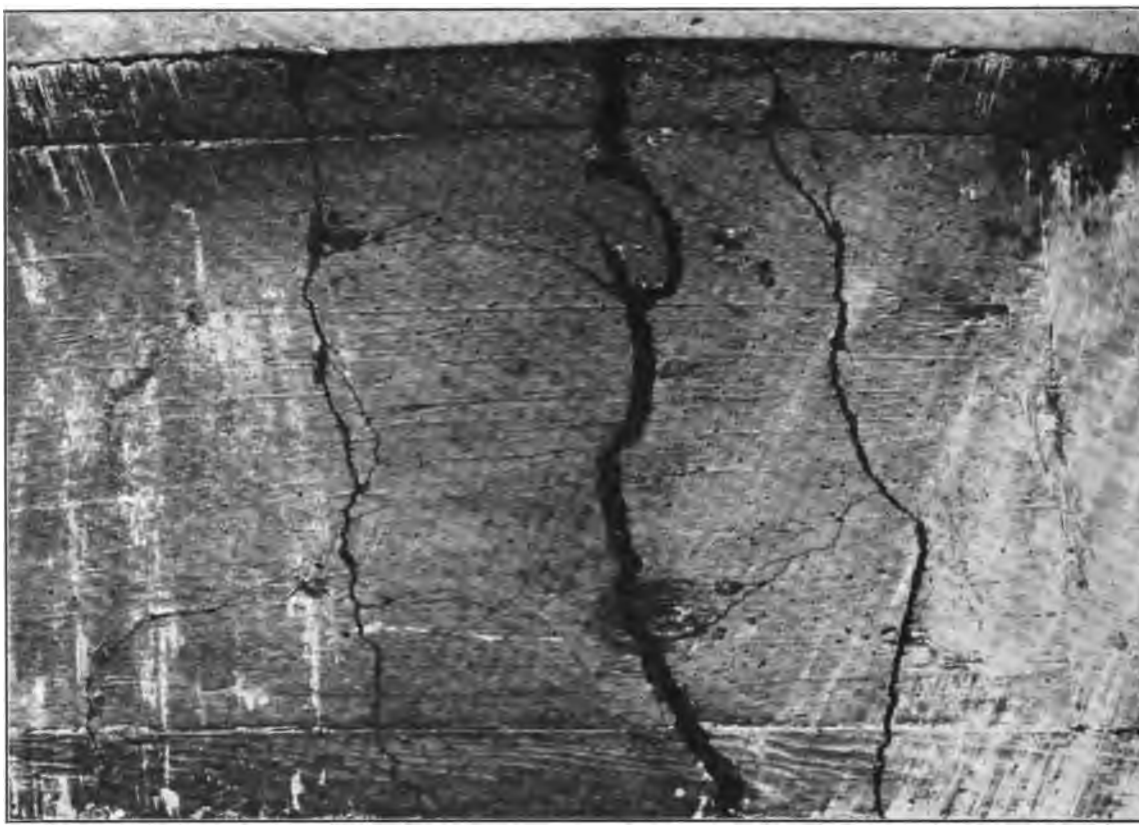


Fig. 6. Slab H-1, two-bar reinforcement

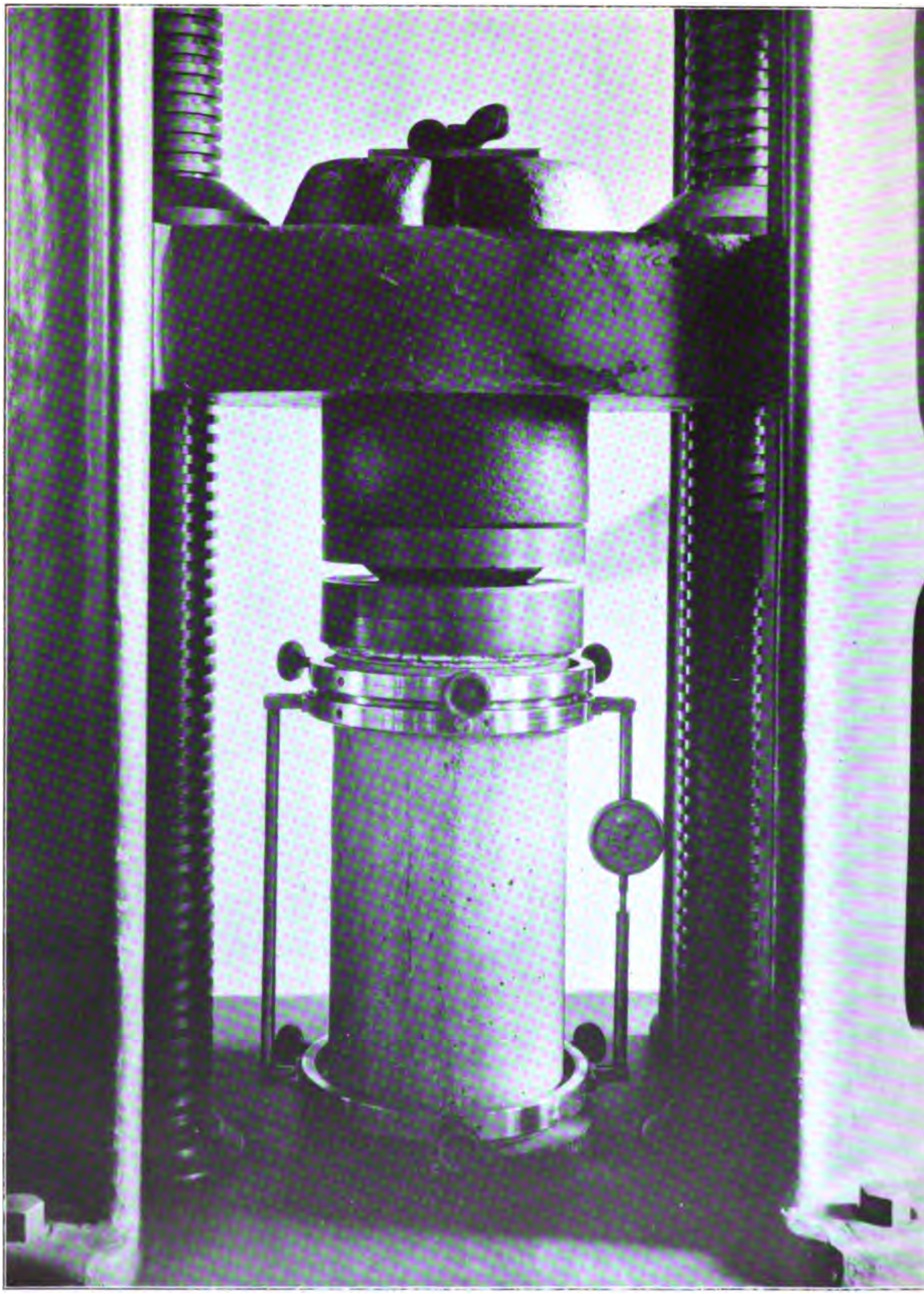


Fig. 7. Cylinder in testing machine showing compressometer attached to specimen

APPENDIX C, PRELIMINARY REPORTS

No. 1 October 15, 1920.

In accordance with the directions in your letter of October 4, 1920, I submit the following statement:

PROPOSED TESTS OF CONCRETE SLABS, 1920

Dimensions:

Thickness 5, 6 and 7 inches. Width of all slabs to be 17 inches. Length of all slabs to be 45 inches.

Age:

Test at 28 days.

Test:

Average of two specimens tested on 42-inch span, load to be applied at the third points.

Mix:

1 part cement to 6 parts aggregate by volume.

Preparation of Specimens:

Mix materials in machine for two minutes after cement, water and aggregates are in mixer. Use enough water for a 3-inch slump. Two days after molding put on a two-inch layer of sand and keep it damp until one week before testing the slabs. Store slabs for the week preceding the test at room temperature.

Aggregates:

Crushed stone, one inch maximum size. American or Yuba River sand.

Reinforcement:

Use mesh 40 lbs. per 100 sq. ft. placed 1½ inches from the bottom of the slab in its testing position.

Supplementary Data:

1. Mold and test 6-inch by 12-inch cylinders of same concrete.
2. Determine Load-Center Deflection curve for each slab.
3. Make sieve analysis of aggregates and test the cement.
4. Measure the fiber stress at the top and bottom of the slab with Berry Strain Gage during progress of the tests on each slab.

(Signed) C. T. WISKOCIL.

No. 2.

PROPOSED TESTS OF CONCRETE PAVEMENT SLABS

October 20, 1920

Dimensions:

Slab thickness 4-inch and 5-inch reinforced vs. 6-inch and 7-inch plain. Width of all slabs 18 inches, length 45 inches.

Age:

Test at 28 days.

Test:

Average of two specimens of each type to be tested on 42-inch spans loaded at third points. There are to be twelve beams in all, two of each type.

Mix:

1 part cement to 6 parts aggregate by volume.

Preparation of Specimens:

Mix materials in machine for two minutes after cement, water and aggregates are in mixer. Use enough water for a three-inch slump.

Curing:

Two days after molding put on a 2-inch layer of sand, keeping it damp until one week before testing the slab. Store slab for the week preceding test at room temperature.

Aggregates:

Crushed rock 1-inch maximum size; American or Yuba River sand.

Reinforcement:

There are to be three sets of beams, A, B and C.

Set A will be plain beams, two 6 inches and two 7 inches thick.

Set B, reinforced with mesh, two 4 inches and two 5 inches thick.

Set C, reinforced with bars, two 4 inches and two 5 inches thick.

For set B the mesh is to be about 40 lbs. per 100 sq. ft. We are proposing a No. 068 American Steel and Wire Co. fabric, which equals about 45 lbs. per 100 sq. ft. For set C, we will use in each slab one 3/8-inch square deformed bar placed at the center of the slab's width. All reinforcement whether bars or mesh is to be placed 1½ inches from the bottom of the slab (in testing position).

Supplementary Data:

1. Determine load center-deflection curve for each slab.
2. Make sieve analysis of aggregates and test cement.

(Signed) C. DERLETH, Jr.

NOTE: The above statement (No. 2) was sent to Messrs. J. B. Lippincott and H. J. Brunnier on October 20, 1920.

No. 3 October 25, 1920.

See earlier statement of October 20, 1920.

REVISED PROGRAM OF TESTS FOR CONCRETE PAVEMENT SLABS

Instead of 12 slabs there are to be 16, as follows:

Set A, two 5-inch plain slabs.

Set B, two 6-inch plain slabs.

Set C, two 7-inch plain slabs.

Set D, two 4-inch slabs reinforced with mesh.

Set E, two 5-inch slabs reinforced with mesh.

Set F, two 4-inch slabs each reinforced with one 3/8-inch square deformed bar placed at the center of the slab's width.

Set G, two 5-inch slabs each reinforced with one 3/8-inch bar as in F.

Set H, two 5-inch slabs each reinforced with two 3/8-inch square deformed bars placed respectively 4½ inches from the sides of the 18-inch slab.

In all other respects the program of tests remains as stated on October 20.

In the Seattle tests a roller 6 inches by 12 inches weighing about 35 lbs. made of concrete, was rolled lengthwise with the slab until the concrete showed no signs of excess water on the surface. We will use practically the same method.

(Signed) C. DERLETH, Jr.

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